



(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
03.09.1997 Bulletin 1997/36

(51) Int. Cl.⁶: H01P 1/20

(21) Application number: 97101988.0

(22) Date of filing: 07.02.1997

(84) Designated Contracting States:
DE FR GB IT

(30) Priority: 01.03.1996 JP 44990/96

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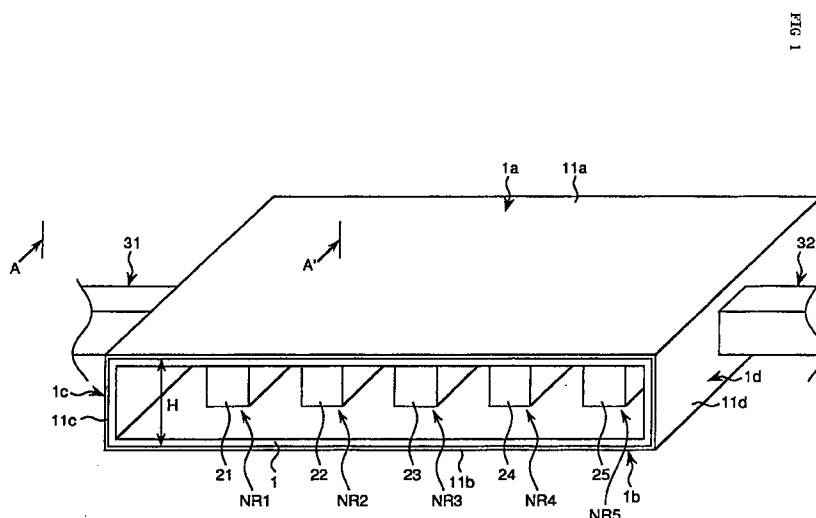
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(54) Dielectric integrated nonradiative dielectric waveguide superconducting band-pass filter apparatus

(57) An NRD waveguide band-pass filter apparatus is provided which is simple in construction and which can be easily manufactured as well as being formed small in size and light in weight, and which operates in a single operating mode. An NRD waveguide band-pass filter apparatus includes a plurality of NRD waveguide resonators arrayed in such a way that two adjacent NRD waveguide resonators are electromagnetic coupled to each other. A plurality of arrayed rectangular dielectric waveguides are interposed between an upper surface portion and a lower surface portion which are parallel to each other. The upper surface portion and the lower

surface portion, and the plurality of arrayed rectangular dielectric waveguides are formed integrally, thus forming a rectangular dielectric housing. A first superconducting electrode and a second superconducting electrode are formed on the outer surface of the upper surface portion and the lower surface portion, respectively. By setting the space between the first and second superconducting electrodes at one half or less of the wavelength of the resonance frequency in a vacuum of the present apparatus, the outer portion of each dielectric waveguide is formed to a cut-off region.



Description**BACKGROUND OF THE INVENTION**

5 1. Field of the Invention

The present invention relates to a dielectric integrated nonradiative dielectric waveguide superconducting band-pass filter apparatus employing nonradiative dielectric waveguides (hereinafter referred to as "NRD waveguides").

10 2. Description of the Related Art

The following arrangement is disclosed in Japanese Unexamined Patent Publication No. 3-270401. When an NRD waveguide such that the upper and lower portions of a dielectric waveguide shaped, for example, in a quadrangular prism are interposed and held by a pair of flat metal plates is formed, the vertical height such that the dielectric member intersects at right angles to the direction of the length is a half-wave length or less, and a brim is extended from one side to the other at the upper and lower end portions in order to form an H shaped cross section, and a metallic film is formed in close contact at the outer surfaces of both upper and lower ends of the dielectric member including the brim portion, thus forming a dielectric integrated NRD waveguide (hereinafter referred to as a "first conventional example"). Such a dielectric integrated NRD waveguide has a feature that even if vibration and/or impact are received, the metal section and the dielectric member are not separated from each other, and stable electrical characteristics can be obtained.

There has been proposed a dielectric-loaded waveguide filter or a waveguide-coupled NRD waveguide in which dielectric resonators at the initial and final stages are directly coupled to the waveguide. In the arrangement of such filters, there is a problem in that it is difficult to adjust the external Q and the resonance frequency independently from each other. In order to solve this problem, in Japanese Unexamined Patent Publication No. 63-59001, a waveguide-coupled NRD guide filter (hereinafter referred to as a "second conventional example") of a type in which an NRD guide resonator and a waveguide are directly coupled is proposed, wherein a buffer dielectric section is disposed in the connection portion of the NRD guide resonator and the waveguide, posterior to a resonator-forming dielectric section of the NRD guide resonator.

An NRD waveguide is formed by using low dielectric-constant materials as materials for dielectric waveguides of an NRD waveguide for use in the first and second conventional examples. However, if an NRD waveguide is formed by using high dielectric-constant materials for the purpose of achieving a smaller size, observation of a phenomenon in which single mode transmission cannot be performed has been reported in prior art reference 1 (Soube Shinohara et al., "Specific Transmission Characteristics of Nonradiative Dielectric Waveguide Using High Dielectric-Constant Materials", Journal of The Institute of Electronics, Information and Communication Engineers of Japan, C-I, Vol.J73-C-I, No.11, pp.716-723, November 1990). The reason why single mode transmission cannot be performed in the conventional NRD waveguide is that a very small gap which cannot be avoided in working, present between the dielectric strip and the metal plate of the NRD waveguide, narrows the band of single mode transmission. In order to solve this problem, in the prior art reference 1, a "trapped insular guide" (hereinafter referred to as a "third conventional example") has been proposed as a structural scheme for an arrangement using high dielectric-constant materials. However, this third conventional example has a problem in that the arrangement is complex, and the manufacturing steps are complex, resulting in a considerable increase in the manufacturing cost.

SUMMARY OF THE INVENTION

45 An object of the present invention is to provide an NRD waveguide band-pass filter apparatus which solves the above-described problems, and which is simple in construction and can be manufactured easily as well as being formed small in size and light in weight, and which operates in a single operating mode.

To achieve the above-described object, according to a first aspect of the present invention, there is provided a dielectric integrated NRD waveguide superconducting band-pass filter apparatus which is an NRD waveguide band-pass filter apparatus having a plurality of NRD waveguide resonators arrayed in such a way that two adjacent NRD waveguide resonators are electromagnetically coupled to each other, the dielectric integrated NRD waveguide superconducting band-pass filter apparatus comprising: a rectangular-cylinder-shaped dielectric housing comprising an upper surface portion and a lower surface portion and a plurality of dielectric waveguides, in which a plurality of arrayed rectangular-cylinder-shaped dielectric waveguides are held by the upper and lower surface portions which are parallel to each other, and the upper and lower surface portions, and the plurality of dielectric sections are formed integrally; a first and a second superconducting electrode formed on each outer surface of the upper surface portion and the lower surface portion, wherein the outer portion of each dielectric waveguide is formed into a cut-off area by setting the space between the first and second superconducting electrodes to one half of the wavelength of the resonance frequency in a vacuum of the band-pass filter apparatus.

According to a second aspect of the present invention, in the dielectric integrated nonradiative dielectric waveguide superconducting band-pass filter apparatus in accordance with the first aspect of the present invention, the dielectric housing further comprises two end surface portions formed in such a manner as to connect both longitudinal ends of the upper surface portion and the lower surface portion, and the band-pass filter apparatus further comprises a third superconducting electrode or metallic electrode formed on the outer surfaces of the two end surface portions.

According to a third aspect of the present invention, in the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the first or second aspect of the present invention, the upper surface portion and the lower surface portion of the dielectric housing, the connection portion between the two end surface portions, and the connection portions between each dielectric waveguide and the upper and lower surface portions are chamfered.

According to a fourth aspect of the present invention, in the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the first, second or third aspect of the present invention, the band-pass filter apparatus further comprises a plane circuit formed on the outer surface of the upper surface portion.

The above and further objects, aspects and novel features of the invention will become more apparent from the following detailed description when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view illustrating the exterior of a dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to a first embodiment of the present invention;

Fig. 2 is a perspective view illustrating the exterior of a dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to a second embodiment of the present invention;

Fig. 3 is a perspective view illustrating the exterior of a dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to a first modification of the present invention;

Fig. 4 is a perspective view illustrating the exterior of a dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to a second modification of the present invention;

Fig. 5 is a front view of the band-pass filter apparatus shown in Fig. 1;

Fig. 6 is a plan view of the band-pass filter apparatus shown in Fig. 1;

Fig. 7A is a longitudinal sectional view illustrating the transmission electromagnetic-field distribution of a TE_{01} mode rectangular waveguide in the band-pass filter apparatus in accordance with the first embodiment, which view is cut by a plane parallel to the transmission direction in the rectangular waveguide;

Fig. 7B is a longitudinal sectional view illustrating the transmission electromagnetic-field distribution of a TE_{01} mode rectangular waveguide in the band-pass filter apparatus in accordance with the first embodiment, which view is cut by a plane vertical to the transmission direction in the rectangular waveguide;

Fig. 7C is a longitudinal sectional view illustrating the transmission electromagnetic-field distribution of a coaxial waveguide in the band-pass filter apparatus in accordance with the second embodiment, which view is cut by a plane passing the axis parallel to the transmission direction in the rectangular waveguide;

Fig. 7D is a longitudinal sectional view illustrating the transmission electromagnetic-field distribution of the coaxial waveguide in the band-pass filter apparatus in accordance with the second embodiment, which view is cut by a plane vertical to the transmission direction in the rectangular waveguide;

Fig. 8A is a longitudinal sectional view illustrating the electric-field distribution of the band-pass filter apparatus in an LSE mode in accordance with the first embodiment, which view is cut by a plane (A-A' in Fig. 1) parallel to the transmission direction in the rectangular waveguide;

Fig. 8B is a longitudinal sectional view illustrating the magnetic-field distribution of the band-pass filter apparatus in an LSE mode in accordance with the first embodiment, which view is cut by a plane (B-B' in Fig. 2) parallel to the transmission direction in the rectangular waveguide;

Fig. 9A is a longitudinal sectional view illustrating the electric-field distribution of the band-pass filter apparatus in an LSM mode in accordance with the second embodiment, which view is cut by a plane passing the axis parallel to the transmission direction in a coaxial waveguide;

Fig. 9B is a longitudinal sectional view illustrating the magnetic-field distribution of the band-pass filter apparatus in an LSM mode in accordance with the second embodiment, which view is cut by a plane passing the axis parallel to the transmission direction in the coaxial waveguide;

Fig. 10A is a perspective view illustrating the electric-field distribution of an LSE_{01} mode transmission waveguide;

Fig. 10B is a perspective view illustrating the magnetic-field distribution of the LSE_{01} mode transmission waveguide;

Fig. 10C is a perspective view illustrating the electric-current distribution of the LSE_{01} mode transmission waveguide;

Fig. 11A is a perspective view illustrating the electric-field distribution of an LSE_{01} mode resonator used in the first embodiment;

Fig. 11B is a perspective view illustrating the magnetic-field distribution of the LSE_{01} mode resonator;
 Fig. 11C is a perspective view illustrating the electric-current distribution of the LSE_{01} mode resonator;
 Fig. 12A is a perspective view illustrating the electric-field distribution of an LSM_{01} mode transmission waveguide;
 Fig. 12B is a perspective view illustrating the magnetic-field distribution of the LSM_{01} mode transmission
 5 waveguide;
 Fig. 12C is a perspective view illustrating the electric-current distribution of the LSM_{01} mode transmission waveguide;
 Fig. 13A is a perspective view illustrating the electric-field distribution of an LSM_{01} mode resonator used in the second embodiment;
 10 Fig. 13B is a perspective view illustrating the magnetic-field distribution of the LSM_{01} mode resonator;
 Fig. 13C is a perspective view illustrating the electric-current distribution of the LSM_{01} mode resonator;
 Fig. 14A is a perspective view illustrating the electric-field distribution of a TE_{10} mode transmission waveguide;
 Fig. 14B is a perspective view illustrating the magnetic-field distribution of the TE_{10} mode transmission waveguide;
 Fig. 14C is a perspective view illustrating the electric-current distribution of the TE_{10} mode transmission waveguide;
 15 Fig. 15A is a perspective view illustrating the electric-field distribution of a TE_{11} mode transmission waveguide;
 Fig. 15B is a perspective view illustrating the magnetic-field distribution of the TE_{11} mode transmission waveguide;
 Fig. 15C is a perspective view illustrating the electric-current distribution of the TE_{11} mode transmission waveguide;
 Fig. 16 is a graph illustrating the temperature characteristics of dielectric loss tangent of ceramic materials having low-loss characteristics at low temperatures;
 20 Fig. 17A is a flowchart illustrating the process flow of an electrode forming process in the superconducting band-pass filter apparatus in accordance with this embodiment;
 Fig. 17B is a flowchart illustrating the process flow of an electrode forming process in the band-pass filter apparatus employing microstrip line resonators in accordance with a comparative example;
 Fig. 18A is a perspective view illustrating the exterior of the microstrip line resonator;
 25 Fig. 18B is a perspective view illustrating the exterior of the NRD waveguide resonator;
 Fig. 19 is a graph illustrating the current density with respect to the position along the width direction (C-C' in Fig. 18A, and D-D' in Fig. 18B) in the microstrip line resonator in Fig. 18A and the NRD waveguide resonator in Fig. 18B;
 Fig. 20A is a plan view illustrating the current density distribution of the NRD waveguide resonator;
 30 Fig. 20B is a plan view illustrating the current density distribution of the TM_{11} mode resonator;
 Fig. 21 is a graph illustrating the frequency characteristics of the attenuation constant of electromagnetic waves when the right-to-left width direction intersecting at right angles to the transmission direction of the dielectric waveguide is observed in the LSE mode, the LSM mode and the TE mode;
 Fig. 22 is a graph illustrating the frequency characteristics of the phase constant in the LSE mode, the LSM mode and the TE mode;
 35 Fig. 23 is a graph illustrating the line width characteristics of the attenuation constant of electromagnetic waves when the right-to-left width direction intersecting at right angles to the transmission direction of the dielectric waveguide is observed in the LSE mode, the LSM mode and the TE mode;
 Fig. 24 is a graph illustrating the line width characteristics in the LSE mode, the LSM mode and the TE mode; and
 40 Fig. 25 is a graph illustrating the characteristics of the coupling coefficient with respect to space S between two arrayed dielectric waveguides.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

45 The preferred embodiments of the present invention will be described below with reference to the accompanying drawings.

Fig. 1 is a perspective view illustrating the exterior of a dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to a first embodiment of the present invention. A front view thereof is shown in Fig. 5, and a plan view thereof is shown in Fig. 6. In Figs. 1, 5 and 6, a dielectric housing 1 made of dielectric materials, such as ceramics having a high dielectric constant, such as $Ba(Sn,Mg,Ta)O_3$ or $(Zr,Sn)TiO_4$, is formed integrally in such a way that dielectric waveguides 21, 22, 23, 24 and 25, each of which has a rectangular-prism shape, are interposingly
 50 disposed between an upper surface portion 1a and a lower surface portion 1b in the shape of flat plates which face each other, with predetermined spaces S (the spaces S are not necessarily equal) each according to a coupling coefficient. Both end portions positioned at the longitudinal end portions of the upper surface portion 1a and the lower surface portion 1b are respectively connected by two end surface portions 1c and 1d, and the longitudinal cross section is formed in a shape like a $\square$ symbol with the entire apparatus being rectangular-cylinder shaped. Here, the dielectric waveguides 21, 22, 23, 24 and 25 are arrayed in such a way that the longitudinal direction thereof is parallel to the direction of the width of the upper surface portion 1a and the lower surface portion 1b, and both longitudinal ends of each of the dielectric waveguides 21, 22, 23, 24 and 25 are separated by a predetermined distance from respective widthwise edges of
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both of the upper surface portion 1a and the lower surface portion 1b. The dielectric housing 1 can be formed by firing, for example, a machined or injection-molded $\text{Ba}(\text{Sn}, \text{Mg}, \text{Ta})\text{O}_3$.

Flat-plate-shaped superconducting electrodes 11a and 11b, which are superconducting thick films which have a thickness of, for example, 3 μm and which are made of superconducting materials of, for example, YBCO (yttrium carbonate), are formed in close contact by an evaporation method at the outer surfaces of the upper surface portion 1a and the lower surface portion 1b, respectively. Flat-plate-shaped superconducting electrodes 11c and 11d, which are superconducting thick films which have the same thickness and materials as those of the superconducting electrodes 11a and 11b, are formed in close contact at two end surface portions 1c and 1d, respectively, by an evaporation method in order to increase the mechanical strength and shield electromagnetic fields. Here, the space H between the superconducting electrodes 1a and 1b which are the upper and lower plane electrodes is set at a half-wave length or less of the center frequency in a vacuum of the relevant filter apparatus. The superconducting electrodes 11c and 11d may be electrodes made from metallic materials of Au, Cu or the like.

As shown in Figs. 8A and 8B, in the central portion of the end surface portion 1c, a rectangular-shaped hole 31h is formed in such a manner as to open in the direction of the thickness of the end surface portion 1c and the electrode 11c. A rectangular waveguide 31 which is formed with an upper surface portion 31a and a lower surface portion 31b which form an E plane, and two side surface portions which form an H plane are connected to the hole 31h by using a flange 31f thereof. Meanwhile, in the central portion of the end surface portion 1d, a rectangular-shaped hole (not shown) is formed in such a manner as to open along the direction of the thickness of the end surface portion 1d and the electrode 11d, and a rectangular waveguide 32 formed with upper and lower surface portions which form an E plane and two side surfaces which form an H plane is connected to the hole by using a flange thereof.

Fig. 7A shows a transmission electromagnetic-field of a rectangular waveguide having a TE_{01} mode. In this embodiment, an LSE_{01} mode resonator is coupled to the TE_{01} mode rectangular resonator, as shown in Figs. 8A and 8B. This is because the electromagnetic-field vector when the LSE_{01} mode resonator is seen from the end surface thereof coincides satisfactorily with the electromagnetic-field within the cross section in the TE_{01} mode. More specifically, the horizontal components of the electric-field vector intersect at right angles to the vertical components of the magnetic-field vector, and the vertical components of the electric-field vector intersect at right angles to the horizontal components of the magnetic-field vector. The direction of the electric-field of the rectangular waveguide coincides with the direction of the electric-field of the resonator, whereas the direction of the magnetic-field of the rectangular waveguide coincides with the direction of the magnetic-field of the resonator.

In the present band-pass filter apparatus, NRD waveguide resonators NR1 to NR5 having an LSE_{01} mode and a predetermined resonance frequency are formed by the dielectric waveguides 21, 22, 23, 24 and 25 interposed between the superconducting electrodes 1a and 1b, and the NRD waveguide resonators NR1 to NR5 are formed as band-pass filters each having a predetermined pass band. Here, two adjacent resonators are electromagnetically coupled, and whereas the rectangular waveguide 31 is electromagnetically coupled to the resonator NR1 at the initial stage, the resonator NR5 at the final stage is electromagnetically coupled to the rectangular waveguide 32. As a result, a band-pass filter apparatus comprising cascaded band-path filters at five stages is disposed between the rectangular waveguide 31 which is an input transmission waveguide and the rectangular waveguide 32 which is an output transmission waveguide.

The upper surface portion 1a and the lower surface portion 1b of the dielectric housing 1 has only the function of supporting the superconducting electrodes 11a and 11b formed on the outer surfaces thereof and does not have the function of forming an NRD waveguide superconducting band-pass filter apparatus. Therefore, the thicknesses t of the upper surface portion 1a and the lower surface portion 1b are formed so as to be sufficiently thin in comparison with the space H between the superconducting electrodes 11a and 11b which are the upper and lower plane electrodes. As a result, it is possible to prevent a phenomenon in which the resonance mode of the NRD resonators which constitute each NRD waveguide band-pass filter is interfered, and the no-load Q deteriorates.

Since the main purpose of the two end surface portions 11c and 11d is to support the superconducting electrodes 11c and 11d (or metallic electrodes) for shielding an electromagnetic field, their thickness is formed sufficiently thin within the range in which the TE_{01} mode mechanical strength is maintained. In this embodiment, the rectangular waveguide is formed so as to be coupled to the side of the LSE_{01} mode resonator, as shown in Figs. 8A and 8B.

In this embodiment, since the superconducting electrodes 11a, 11b, 11c and 11d are used, the ambient temperature of the present apparatus is cooled to a low temperature of, for example, 77K by using nitrogen gas or the like so that the superconducting electrodes 11a, 11b, 11c and 11d are operated with a low loss.

Next, a method of setting each parameter in the filter apparatus of this embodiment will be described with reference to the accompanying drawings.

Fig. 21 is a graph illustrating the frequency characteristics of the attenuation constant of electromagnetic waves when the right-to-left width direction of the dielectric waveguide intersecting at right angles to the transmission direction thereof is seen in the LSE mode, the LSM mode and the TE mode. The calculation conditions for simulation in Fig. 21 are set as follows: a space H of 5.0 mm between each pair of dielectric waveguides 21 to 25, a width W of 2.5 mm, and a specific inductive capacity ϵ_r of 24.

Fig. 22 is a graph illustrating the frequency characteristics of the phase constant in the LSE mode, the LSM mode and the TE mode. The calculation conditions for simulation in Fig. 22 are set as follows: a space H of 5.0 mm between each pair of dielectric waveguides 21 to 25, a width W of 2.5 mm, and a specific inductive capacity ϵ_r of 24.

Fig. 23 is a graph illustrating the frequency characteristics of the attenuation constant of electromagnetic waves when the right-to-left width direction intersecting at right angles to the transmission direction of the dielectric waveguide is observed in the LSE mode, the LSM mode and the TE mode. The calculation conditions for simulation in Fig. 23 are set as follows: a space H of 5.0 mm between each pair of dielectric waveguides 21 to 25, a frequency f_0 of 12 GHz, and a specific inductive capacity ϵ_r of 24.

Fig. 24 is a graph illustrating the waveguide width characteristics in the LSE mode, the LSM mode and the TE mode. The calculation conditions for simulation in Fig. 24 are set as follows: a space H of 5.0 mm between each pair of dielectric waveguides 21 to 25, a frequency f_0 of 12 GHz, and a specific inductive capacity ϵ_r of 24.

Fig. 25 is a graph illustrating the characteristics of the coupling coefficient with respect to the space S of two arrayed dielectric waveguides. The calculation conditions for simulation in Fig. 25 are set as follows: a space H of 5.0 mm between each pair of dielectric waveguides, a width W of 2.5 mm, and a specific inductive capacity ϵ_r of 24.

(1) Space H between the superconducting electrodes 11a and 11b

The space H is set to one half the resonance wavelength or less in a vacuum of the present filter apparatus. By setting the space H to such limitation conditions, it is possible to set the space between the dielectric waveguides, i.e., the outer portion of each pair of dielectric waveguides 21 to 25, to be a cut-off region.

(2) Width W of the dielectric waveguides 21 to 25

The width W of the dielectric waveguides 21 to 25 determines the attenuation constant of waves when seen from the right-to-left width direction intersecting at right angles to the transmission direction. For example, in a case of a waveguide having a space H of 5.0 mm using a dielectric material having a specific dielectric constant ϵ_r of 24, when the frequency is 12 GHz, the attenuation constants are as shown in Fig. 23, and by increasing the width W of the waveguide, it is possible to sharpen the attenuation in the width direction. Also, as shown in Fig. 21, the higher the frequency, the greater the attenuation constant of each mode. Furthermore, as shown in Fig. 24, the phase constant of each mode reaches a saturated state when the width W of the dielectric waveguide increases to a certain degree.

(3) Lengths L of the dielectric waveguides 21 to 25

The lengths L of the dielectric waveguides 21 to 25 are determined on the basis of resonance frequencies to be set in each of the resonators NR1 to NR5. The resonance frequencies are determined so that the dielectric waveguides 21 to 25 resonate at substantially a half-wave length or an integral multiple of a half-wave length, including attenuated waves, in the front-to-back direction when seen from the end surface, with respect to the length L of the dielectric waveguides 21 to 25.

(4) Space S between each pair of dielectric waveguides 21 to 25

The space S between each pair of dielectric waveguides 21 to 25 determines the coupling coefficient between two adjacent resonators. As shown in Fig. 25, the narrower the space S of the waveguides and the smaller the attenuation constant in the cut-off region, the greater the coupling coefficient. The graph in Fig. 25 shows the coupling coefficient K, with the waveguide space S as a variable, in a case where the NRD waveguide resonators NR1 to NR5 are formed using materials of a specific dielectric constant ϵ_r of 24 with a space H of 5.0 mm and a waveguide width W of 2.5 mm. As is clear from Fig. 25, when the waveguide space S is set at 5.0 mm, the coupling coefficient K becomes approximately 0.4%.

(5) Thickness t of each of the sections 11a, 11b, 11c and 11d of the dielectric housing 1, formed using dielectric materials

The thickness t is set so as to maintain the mechanical strength required to perform the above-described functions. When the thickness t is thick to a certain degree in comparison with the space H, there is a tendency for the sharpness of the attenuation constant in the cut-off region to decrease, and the coupling coefficient K to increase.

The frequency characteristics (i.e., the divergence relation) of the phase constants of the NRD waveguide resonators constructed as described above are as shown in Fig. 22. As is clear from Fig. 22, a TE_{10} mode (basic mode), a secondary LSE_{01} mode, and a tertiary LSM_{01} mode occur in this order starting from the low frequency side. The LSE_{01} mode and the LSM_{01} mode have cut-off frequencies f_{c1} and f_{c2} , respectively; however, in the TE_{10} mode, propagation is based on a direct current. Therefore, in the first embodiment, when, for example, a resonator having an LSE_{01} mode is formed, a resonator having an LSE_{01} mode as a main mode can be formed by setting the center frequency of the present filter preferably between the cut-off frequency f_{c1} and the cut-off frequency f_{c2} and by adjusting each of the above-described parameters so as to suppress spurious modes other than the LSE_{01} mode. Also, in the second embodiment, when, for example, a resonator having an LSM_{01} mode is formed, a resonator having an LSM_{01} mode as a main mode can be formed by setting the center frequency of the present filter apparatus to the cut-off frequency f_{c2} or higher and by adjusting each of the above-described parameters so as to suppress spurious modes other than the LSM_{01} mode.

Next, the electric-field distribution, magnetic-field distribution, and electric-current distribution in the transmission mode of each transmission waveguide are shown in Figs. 10A and 10B, Figs. 12A, 12B, and 12C, and Figs. 14A, 14B, and 14C, respectively. A description will be given below of the electric-field, magnetic-field, and electric-current distributions in the transmission mode of each transmission waveguide.

(A1) Transmission waveguide (Figs. 10A, 10B and 10C) in the LSE_{01} mode

In the LSE_{01} mode, an electric-field vector is present only within the plane parallel to the propagation direction and vertical to the superconducting electrodes 11a and 11b which are the upper and lower electrodes. Electric currents I are generated in the central portion of the electrodes 11a and 11b which correspond to the upper and lower surfaces of a dielectric waveguide 26 in such a manner as to be parallel to the propagation direction and with the directions being aligned. Further, at a position deviated by a half-wave length, the front-to-back directions of the electric currents I interchange. The superconducting electrodes 11c and 11d on the side are provided for the purpose of shielding electromagnetic fields, and substantially transmission electric currents I do not flow through these electrodes 11c and 11d.

(A2) Transmission waveguide (Figs. 12A, 12B and 12C) in the LSM_{01} mode

In the LSM_{01} mode, a magnetic-field vector is present only within the plane parallel to the propagation direction and vertical to the superconducting electrodes 11a and 11b which are the upper and lower electrodes. Electric currents I are generated in the central portion of the electrodes 11a and 11b on the upper and lower surfaces of a dielectric waveguide 27 in such a manner as to be parallel to the propagation direction and with the directions being aligned. Further, at a position deviated by a half-wave length, the right-to-left directions of the electric currents I interchange. The superconducting electrodes 11c and 11d on the sides are provided for the purpose of shielding electromagnetic fields, and substantial transmission electric currents I do not flow through these electrodes 11c and 11d.

(A3) Transmission waveguide (Figs. 14A, 14B and 14C) in the TE_{10} mode

In the TE_{10} mode, an electric-field vector is present only within the plane vertical to the propagation direction. An electric current I flows radially from the central portion (of a waveguide 28) of a superconducting electrode 11a on the upper surface, and flows through the superconducting electrodes 11c and 11d on the side toward the central portion of the electrode 11b on the lower surface. Further, at a position deviated by a half-wave length, the directions of the electric currents I of the superconducting electrodes 11a and 11b on the upper and lower surfaces interchange. Therefore, the electrodes 11c and 11d on the sides play an essentially necessary role in causing transmission electric current I to flow.

Furthermore, Figs. 11A, 11B, and 11C, Figs. 13A, 13B, and 13C and Figs. 15A, 15B, and 15C show respectively the electric-field distribution, the magnetic-field distribution, and the electric-current distribution in the resonance mode of each half-wave-length resonator in which dielectric waveguides for each transmission mode are cut to a finite length and the front-to-back region becomes a cut-off region. However, the LSE_{01} mode used in the first embodiment and the LSM_{01} mode used in the second embodiment resonate at a half-wave length under an open condition, and the TE_{10} mode resonates at a half-wave length under a short-circuit condition. Generally, such a resonator structure is called a TM_{11} mode by regarding the height direction to be the transmission direction.

(B1) LSE_{01} mode resonator (Figs. 11A, 11B and 11C)

In the LSE_{01} mode used in the first embodiment, electromagnetic-field energy concentrates within a dielectric waveguide 20a, and the outer portion around the dielectric waveguide 20a is a cut-off region; therefore energy confinement characteristics are excellent. Electric currents I are generated centered in the central portion (of each waveguide) of the superconducting electrodes 11a and 11b which are the upper- and lower-surface electrodes of the dielectric waveguide 20a. The electric currents I of the superconducting electrodes 11a and 11b on the upper and lower surfaces flow in the same direction with a plane symmetry and do not intersect each other. The electrodes 11c and 11d on the sides are provided for shielding electromagnetic fields, and substantial transmission electric currents I do not flow through the electrodes 11c and 11d on the sides.

(B2) LSM_{01} mode resonator (Figs. 13A, 13B and 13C)

The LSM_{01} mode used in the second embodiment is of a higher-order mode than LSE_{10} , and the resonator operates in the same way as the LSE_{01} mode resonator at frequencies higher than the cut-off frequency. More specifically, electromagnetic-field energy concentrates within a dielectric waveguide 20b, and the outer portion around the dielectric waveguide 20b is a cut-off region; therefore, energy confinement characteristics are excellent. Electric currents I are generated centered in the central portion of the superconducting electrodes 11a and 11b which are the upper- and lower-surface electrodes of the dielectric waveguide 20b. The electric currents I of the superconducting electrodes 11a and 11b which are the upper- and lower-surface electrodes flow in the same direction with a plane symmetry and do not intersect each other. The electrodes 11c and 11d on the side are provided for shielding electromagnetic fields, and substantial transmission electric currents I do not flow through the electrodes 11c

and 11d on the sides.

(B3) TM_{11} mode resonator (Figs. 15A, 15B and 15C)

In the TM_{11} mode, a concentrated electric-field vector is parallel to the height direction of the dielectric waveguide 28. An electric current I flows radially from the central portion of the electrode 11a of the upper surface, and flows through the electrodes 11c and 11d on the sides toward the central portion of the electrode 11b on the lower surface. Further, at a position out of a half cycle, the directions of the electric currents I interchange. Therefore, the electrodes 11a and 11b on the side play an essentially necessary role for causing electric current I to flow.

In the first embodiment, a band-pass filter apparatus is formed by using the above-described LSE_{01} mode resonator, whereas in the second embodiment, a band-pass filter apparatus is formed by using the above-described LSM_{01} mode resonator. Concerning the mode notation convention for the LSE and LSM modes in the present specification, the first subscript indicates the number of nodes in the width direction, and the second subscript indicates the number of nodes in the height direction.

Fig. 2 is a perspective view illustrating the exterior of a dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to a second embodiment of the present invention. The difference points of the second embodiment from the first embodiment are that coaxial connectors 41 and 42 are provided as input/output terminals, and a coaxial waveguide 43 is used as a transmission waveguide. The difference points will be described below.

As shown in Fig. 2, in the central portion of the end surface portion 1c on the side, a circular-shaped hole 41h is formed so as to open along the thickness direction of the end surface portion 1c and the electrode 11c. A coaxial connector 41 having a center conductor 41c is inserted into that hole 41h by using a ring 41f of the coaxial connector 41. A coaxial plug 43p is attached to the end portion of the coaxial waveguide 43 comprising a center conductor 43a and a grounding conductor 43b, and the coaxial plug 43p is inserted into the coaxial connector 41, thus the coaxial waveguide 43 is connected to the coaxial connector 41. Here, the center conductor 43a of the coaxial waveguide 43 is connected to the center conductor 41c of the coaxial connector 41, and the grounding conductor 43b of the coaxial waveguide 43 is connected to the electrode 11c via the ring 41f of the coaxial connector 41. Meanwhile, in the central portion of the end surface portion 1d on the side, a circular-shaped hole (not shown) is formed so as to open along the thickness direction of the end surface portion 1d and the electrode 11d, a coaxial connector 42 is inserted into that hole, and a coaxial waveguide (not shown) is connected to the coaxial connector 42.

The transmission electromagnetic-field distribution in the coaxial waveguide 43 is as shown in Fig. 7B. The coaxial waveguide 43 is electromagnetically coupled to the LSM_{01} mode resonator NR1 at the initial stage via the coaxial connector 41 as shown in Figs. 9A and 9B. In a similar manner, the LSM_{01} mode resonator NR5 at the final stage is electromagnetically coupled to the coaxial waveguide via the coaxial connector. That is, the LSM_{01} mode resonator is coupled to the coaxial waveguide having a TEM transmission mode. This is because the electromagnetic-field vector when the LSM_{01} mode resonator is observed from the end surface thereof coincides satisfactorily with the electromagnetic-field within the cross section in the TEM mode. More specifically, the electric-field vector of the coaxial waveguide 43 has radius vector components which expand radially, the magnetic-field vector thereof has components in the direction of coaxial rotation, and they intersect at right angles to each other. As described above, since the shape of the electromagnetic-field vector of the LSM_{01} mode of the resonator is similar to that of the cross-sectional electromagnetic-field vector of the transmission mode, an easy-to-connect structure is formed as an input/output structure.

Fig. 3 is a perspective view illustrating the exterior of a dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to a first modification of the present invention. In this first modification, as compared with the first embodiment, corners 2 in the connecting portions between the upper surface portion 1a and the end surface portions 1c and 1d and in the connecting portions between the lower surface portion 1b and the end surface portions 1c and 1d are chamfered so as to form a slope. Meanwhile, the bonding portions 3 between the dielectric waveguides 21, 22, 23, 24 and 25 on the one side, and the upper surface portion 1a and the lower surface portion 1b on the other are chamfered to be rounded so that a curved line is formed from the side surfaces of the dielectric waveguides 21, 22, 23, 24 and 25 to the upper surface portion 1a and the lower surface portion 1b. As a result, the effect of preventing cracks when stresses occur in dielectric materials, and the effect of increasing mechanical strength can be expected. Factors in which stresses occur in dielectric materials are present in cases where a sharp, partial temperature change is given, for example, in a case in which an increase in temperature when an electrode is formed as a film has a distribution, causing a part of the electrode to expand, or in a case where a decrease in temperature when a superconducting filter is cooled to about 77K has a distribution, causing a part of the superconducting filter to contract. Forming a dielectric integrated type superconducting band-pass filter apparatus in the above-described way makes stable operation possible when this apparatus is cooled from room temperature (about 300K) to nitrogen temperature (about 77K) so as to operate at a low temperature.

The chamfering in the above-described first modification may be performed so as to form a slope or plane surface. The operation of the filter apparatus of the first and second embodiments is as follows.

(1) Such filters operate as band-pass filters in the microwave and millimetric-wave band.

(2) Superconducting electrodes operate with low loss at low temperatures.

(3) NRD waveguides having predetermined dimensions resonate at an integral multiple of a half-wave length, and their ambient regions operate as cut-off regions.

(4) Resonance current concentrates in the electrodes 11a and 11b on the upper and lower surfaces of the NRD waveguide, and electric current to the electrode edge portions is not present.

(5) Such filters operate with the same effects and advantages with respect to two independent modes of LSE and LSM.

The details of the effects and advantages of the first and second embodiments are as follows.

(1) High reliability

Linear expansion coefficients of ceramic materials are shown in Table 1, and linear expansion coefficients of metallic materials are shown in Table 2.

Table 1

Linear expansion coefficients of ceramic materials		
Ceramic Materials	Specific Inductive Capacity ϵ_r	Linear Expansion Coefficient ppm/K
(Zr,Sn)TiO ₄	38	6 to 7
Ba(Sn,Mg,Ta)O ₃	24	10.7

Table 2

Linear expansion coefficients of metallic materials (Cited from "Science Chronological Table" (1995) edited by Japanese National Astronomical Observatory)		
Metallic materials	100K	293K
Copper	10.3	16.5
Brass	-	17.5
Stainless steel	11.4	14.7

As is clear from Tables 1 and 2, ceramic materials, such as (Zr,Sn)TiO₄ or Ba(Sn,Mg,Ta)O₃, have a linear expansion coefficient substantially smaller than that of metallic materials. Further, since each section is formed integrally in the dielectric housing 1 made from ceramic materials, the linear expansion coefficient of the present dielectric housing 1 is constant, and this is deformed analogously when the filter apparatus is cooled. Therefore, even if the apparatus is operated at low temperatures, the reliability of the electrical operations of the filter apparatus is high because internal stress is small, and problems with cracks in the ceramic materials or the like do not occur.

(2) Low-loss characteristics

As materials for the dielectric housing 1, dielectric materials with a low loss at low temperatures, such as Ba(Sn,Mg,Ta)O₃ or (Zr,Sn)TiO₄, are used. Therefore, when a superconducting band-pass filter apparatus is formed, the low-loss characteristics of superconducting electrodes effectively act in determining the performance of the filter. To be specific, when YBCO is used, the surface resistance value is approximately 10 m ω at 10 GHz and 50K. The electrical characteristic values in an example of dielectric materials are as follows.

(2A) Ba(Sn,Mg,Ta)O₃: $\epsilon_r = 24$, $\tan \delta = 0.114 \times 10^{-4}$ (at a frequency of 10 GHz and a temperature of 77K)

(2B) (Zr,Sn)TiO₄: $\epsilon_r = 38$, $\tan \delta = 0.525 \times 10^{-4}$ (at a frequency of 10 GHz and a temperature of 77K)

Further, the temperature characteristics of the dielectric loss tangent of the above-described two dielectric materials are shown in Fig. 16. As can be seen in Fig. 16, the dielectric loss tangent is exceedingly small at relatively low temperatures.

(3) Ease of process

For example, in a case of a microstrip line resonator of a comparative example shown in Fig. 18A, six processes from steps S11 to S16 are required, as shown in Fig. 17B. On the other hand, for superconducting electrodes of this embodiment, at least only the upper and lower electrodes 11a and 11b of the present apparatus need to be formed; therefore, as shown in Fig. 17A, it is possible to use only one step S1 of a simple film-forming process on a flat surface. Further, since fine-pattern processing is not required, processing accuracy does not pose a problem, and the reliability of processing accuracy is high.

(4) Electric-power resistivity

Fig. 19 is a graph illustrating the current density with respect to the position along the width direction in the microstrip line resonator of the comparative example shown in Fig. 18A and the NRD waveguide resonator of the embodiment shown in Fig. 18B. As is clear from Fig. 19, in the comparative example, abnormal divergence of electric current appears due to the edge effect in edge portions 52a and 52b, and a superconducting state is destroyed in the edge portions when superconducting electrodes are used; however, in this embodiment, there is no abnormal current concentration to the electrode edge portions due to the edge effect. Therefore, even if a large power is input to the superconducting band-pass filter apparatus at the critical current density (J_c) or less of the superconducting electrode, the filter apparatus is able to operate, and thus it can easily cope with a large amount of power.

(5) Low-distortion characteristics

As described above, since there is no abnormal current concentration in the electrode edge portions due to the edge effect, the linearity of electric power is improved, for example, the mutual modulation distortion becomes small.

(6) Small-size designability

As is clear from Figs. 20A and 20B which illustrate the relative level of the current amplitude with respect to the maximum value of the current amplitude, in the NRD waveguide resonator of this embodiment, energy concentrates in the dielectric waveguide as compared with the TM_{11} mode resonator of the comparative example, and the attenuation is rapid in the ambient cut-off region. Therefore, it is possible to set the coupling coefficient K between the resonators to be smaller than that of the TM mode resonator, and the filter apparatus can be made smaller in size and lighter in weight than the TM mode resonator.

(7) Thin-type designability

The insertion loss of the band-pass filter apparatus is almost inversely proportional to the space H between the upper and lower plane electrodes 11a and 11b; however, thin-type design is made possible by forming plane electrodes to be superconductive.

(8) Hybrid formation with plane circuit

As shown in a second modification of Fig. 4, the surfaces of the superconducting electrodes 11a and 11b can be used in common as grounding electrodes of the other plane circuits. Therefore, it is possible to form on the surface of the filter apparatus high-frequency signal processing circuit modules, for example, oscillation circuits, frequency conversion circuits, multiplication circuits or amplification circuits. In the example shown in Fig. 4, after a dielectric layer 4 is formed on the superconducting electrode 11a, a pattern electrode 5 and a terminal electrode 6 are formed on the dielectric layer 4, thus forming a plane circuit.

Although the above embodiments describe a band-pass filter apparatus with a five-stage structure, the present invention is not limited to this example and may be a band-pass filter apparatus with at least one stage.

Although the above embodiments describe a case in which superconducting electrodes 11c and 11d are formed on the sides or on the end surfaces, the present invention is not limited to this example, and these electrodes may not be formed.

Each parameter in the embodiment of the superconducting band-pass filter apparatus employing the LSE_{01} mode resonator of the first embodiment is shown below.

- (a) Number of filter stages: 5
- (b) Center frequency: 12 GHz
- (c) Designed band width: 24 MHz
- (d) Ripple: 0.01 dB
- (e) Operating temperature: 77K
- (f) Specific inductive capacity of dielectric materials: 24
- (g) Space H between superconducting electrodes: 5.0 mm
- (h) Width W of dielectric waveguides: 2.5 mm
- (i) Space S between dielectric waveguides: 6.0 mm
- (j) Length L of dielectric waveguides: 4.2 mm
- (k) Filter exterior dimensions = height: 7.0 mm; width: 60.0 mm; depth: 15.0 mm

The inventors of the present invention realized the band-pass filter apparatus of the first embodiment by setting as

described above.

In this embodiment, the width W , the space S and the length L of the dielectric waveguides are fixed values; however, needless to say, this embodiment may be embodied by adjusting the respective dimensions for the purpose of adjusting characteristics.

As has been described above in detail, the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the first aspect of the present invention is an NRD waveguide band-pass filter apparatus having a plurality of NRD waveguide resonators arrayed in such a way that two adjacent NRD waveguide resonators are electromagnetically connected to each other, the dielectric integrated NRD waveguide superconducting band-pass filter apparatus comprising: a rectangular-cylinder-shaped dielectric housing including an upper surface portion and a lower surface portion, and a plurality of dielectric waveguides, in which a plurality of arrayed rectangular-cylinder-shaped dielectric waveguides are interposed between the upper surface portion and the lower surface portion which are parallel to each other, and the upper and lower surface portions, and the plurality of dielectric waveguides are formed integrally; and a first and a second superconducting electrode formed on each outer surface of the upper surface portion and the lower surface portion, wherein the outer portion of each dielectric waveguide is formed into a cut-off region by setting the space between the first and second superconducting electrodes to one half or less the wavelength of the resonance frequency in a vacuum of the band-pass filter apparatus. Therefore, it is possible to provide an NRD waveguide band-pass filter apparatus which is simple in construction and which can be easily manufactured as well as being formed small in size and light in weight, and which operates in a single operating mode. The details of the advantages which are characteristic of the present invention are as follows.

(1) High reliability

As is clear from Tables 1 and 2, ceramic materials, such as $(\text{Zr}, \text{Sn})\text{TiO}_4$ or $\text{Ba}(\text{Sn}, \text{Mg}, \text{Ta})\text{O}_3$, have a linear expansion coefficient substantially smaller than that of metallic materials. Further, since each section is formed integrally in the dielectric housing 1 made from ceramic materials, the linear expansion coefficient of the present dielectric housing 1 is constant, and this is deformed analogously when the filter apparatus is cooled. Therefore, even if the filter apparatus is operated at low temperatures, the reliability of the electrical operations of the filter apparatus is high because internal stress is small, and problems, such as cracking of the ceramic materials or the like, do not occur.

(2) Low-loss characteristics

As materials for the dielectric housing 1, dielectric materials with low loss at low temperatures, such as $\text{Ba}(\text{Sn}, \text{Mg}, \text{Ta})\text{O}_3$ or $(\text{Zr}, \text{Sn})\text{TiO}_4$, are used. Therefore, when a superconducting band-pass filter apparatus is formed, the low-loss characteristics of superconducting electrodes effectively act in determining the performance of the filter. To be specific, when YBCO is used, the surface resistance value is approximately $10 \text{ m}\Omega$ at 10 GHz and 50K.

(3) Ease of process

For example, in a case of a microstrip line resonator of a comparative example, six processes from steps S11 to S16 are required, as shown in Fig. 17B. On the other hand, for superconducting electrodes of this embodiment, at least only the upper and lower electrodes 11a and 11b of the present apparatus need to be formed; therefore, as shown in Fig. 17A, it is possible to use only one step S1 of a simple film-forming process on a flat surface. Further, since fine-pattern processing is not required, processing accuracy does not pose a problem, and the reliability of processing accuracy is high.

(4) Electric-power resistivity

As is clear from Fig. 19, in the microstrip line resonator of the comparative example, abnormal divergence of electric current appears due to the edge effect in the edge portions 52a and 52b; however, in this embodiment, there is no abnormal current concentration in the electrode edge portions due to the edge effect. Therefore, even if a large power is input to the superconducting band-pass filter apparatus at the critical current density (J_c) or less of the superconducting electrode, the filter apparatus is able to operate, and thus it can easily cope with a large amount of power.

(5) Low-distortion characteristics

As described above, since there is no abnormal current concentration in the electrode edge portions due to the edge effect, linearity of electric power is improved, for example, mutual modulation distortion becomes small.

(6) Small-size designability

As is clear from Figs. 20A and 20B which illustrate the relative level of the current amplitude with respect to the maximum value of the current amplitude, in the NRD waveguide resonator of the present invention, energy concentrates in the dielectric waveguide as compared with the TM_{11} mode resonator of the comparative example, and attenuation is rapid in the ambient cut-off region. Therefore, it is possible to set coupling coefficient K between the resonators to be smaller than that of the TM mode resonator, and the filter apparatus can be made smaller in size and lighter in weight than the TM mode resonator.

(7) Thin-type designability

The insertion loss of the band-pass filter apparatus is almost inversely proportional to the space H between the upper and lower plane electrodes 11a and 11b; however, thin-type design is made possible by forming plane electrodes to be superconductive.

According to the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the second aspect of the present invention, in the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the first aspect of the present invention, the dielectric housing further comprises two end surface portions formed in such a manner as to connect both longitudinal ends of the upper surface portion and the lower surface portion, and the band-pass filter apparatus further comprises a third superconducting or metallic electrode formed on the outer surfaces of the two end surface portions. Therefore, since the interior of the present band-pass filter apparatus can be electromagnetically shielded from the outside, it is possible to prevent entry of interference and disturbing waves from the outside, and thus the band-pass filter apparatus operates stably.

Further, according to the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the third aspect of the present invention, in the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the first or second aspect of the present invention, the upper surface portion and the lower surface portion of the dielectric housing, the connecting portion between the two end surface portions, and the connecting portions between each dielectric waveguide and the upper and lower surface portions are chamfered. As a result, the effect of preventing cracks when stresses occur in dielectric materials, and the effect of increasing mechanical strength can be expected. Factors in which stresses occur in dielectric materials are present in cases where a sharp, partial temperature change is given, for example, in a case in which an increase in temperature when an electrode is formed as a film has a distribution, causing a part of the electrode to expand, or in a case where a decrease in temperature when a superconducting filter is cooled to about 77K has a distribution, causing a part of the superconducting filter to contract. Forming a dielectric integrated type superconducting band-pass filter apparatus in the above-described way makes stable operation possible when the apparatus is cooled from room temperature (about 300K) to nitrogen temperature (about 77K) for low temperature operation.

Furthermore, according to the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the fourth aspect of the present invention, in the dielectric integrated NRD waveguide superconducting band-pass filter apparatus in accordance with the first, second or third aspect of the present invention, the band-pass filter apparatus further comprises a plane circuit formed on the outer surface of the upper surface portion. Therefore, a plane circuit module for high-frequency signal processing can be formed on the surface of the filter apparatus, and the entire apparatus can be formed in a small size and light weight.

Many different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention. It should be understood that the present invention is not limited to the specific embodiments described in this specification. To the contrary, the present invention is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the invention as hereafter claimed. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications, equivalent structures and functions.

Claims

1. A dielectric integrated nonradiative dielectric (NRD) waveguide superconducting band-pass filter apparatus having a plurality of NRD waveguide resonators arrayed in such a way that two adjacent NRD waveguide resonators are electromagnetically connected to each other, said dielectric integrated NRD waveguide superconducting band-pass filter apparatus comprising:

a rectangular-cylinder-shaped dielectric housing comprising an upper surface portion and a lower surface portion, and a plurality of dielectric waveguides, in which a plurality of arrayed rectangular-cylinder-shaped dielectric waveguides are interposed between the upper surface portion and the lower surface portion which are parallel to each other, and the upper surface portion and the lower surface portion, and the plurality of dielectric waveguides are formed integrally; and

a first and a second superconducting electrode formed on each outer surface of the upper surface portion and the lower surface portion, wherein the outer portion of said each dielectric waveguide is formed into a cut-off region by setting the space between the first and second superconducting electrodes to one half or less of the wavelength of the resonance frequency in a vacuum of said band-pass filter apparatus.

2. A dielectric integrated NRD waveguide superconducting band pass filter apparatus according to claim 1, wherein said dielectric housing further comprises two end surface portions formed in such a manner as to connect both longitudinal ends of the upper surface portion and the lower surface portion, and said band-pass filter apparatus further comprises a third superconducting electrode or metallic electrode formed on the outer surfaces of said two end

surface portions.

3. A dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to one of claims 1
and 2, wherein the upper surface portion and the lower surface portion of said dielectric housing, the connecting
portion between said two end surface portions, and the connecting portions between said each dielectric
waveguide and said upper and lower surface portions are chamfered.

4. A dielectric integrated NRD waveguide superconducting band-pass filter apparatus according to one of claims 1 to
3, wherein said band-pass filter apparatus further comprises a plane circuit formed on the outer surface of said
upper surface portion.

FIG 1

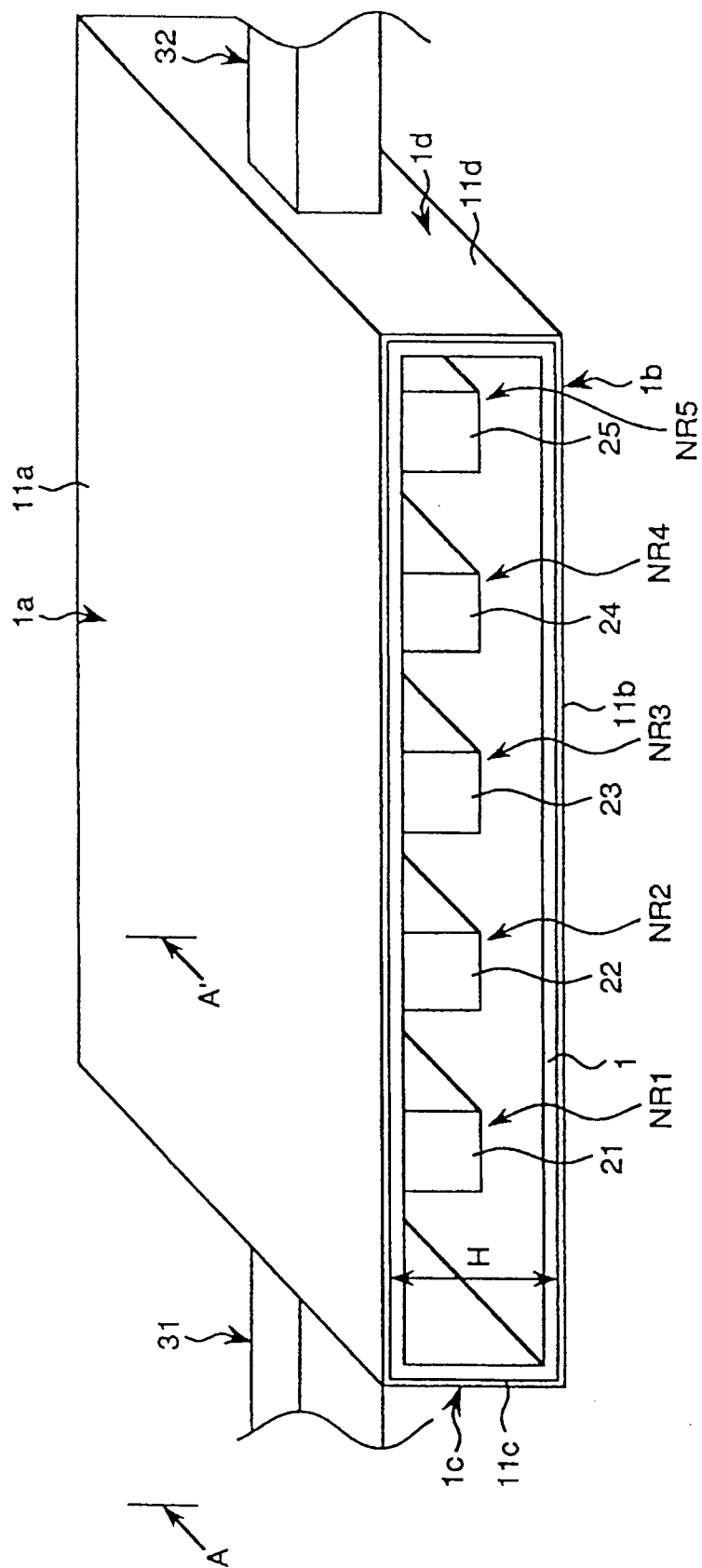


FIG. 2

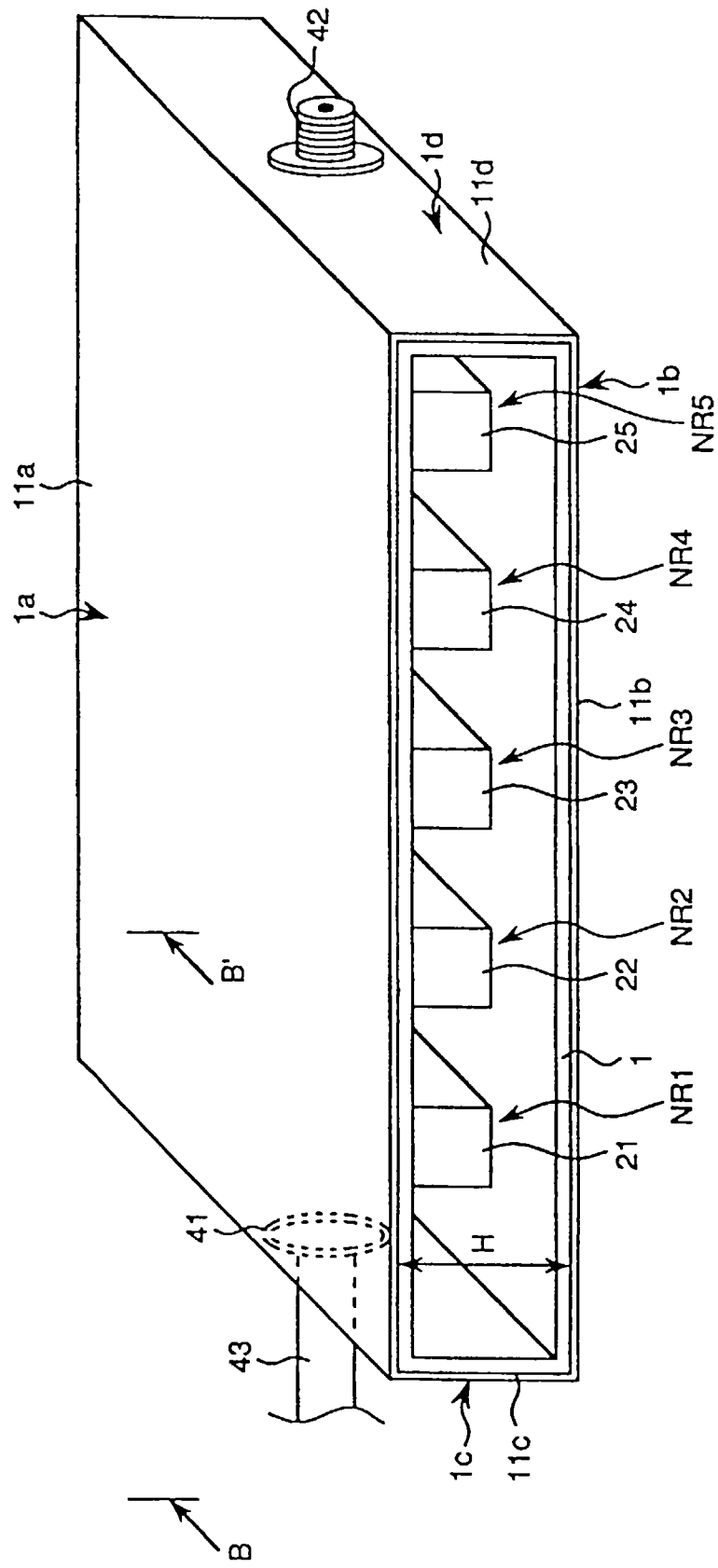


FIG. 3

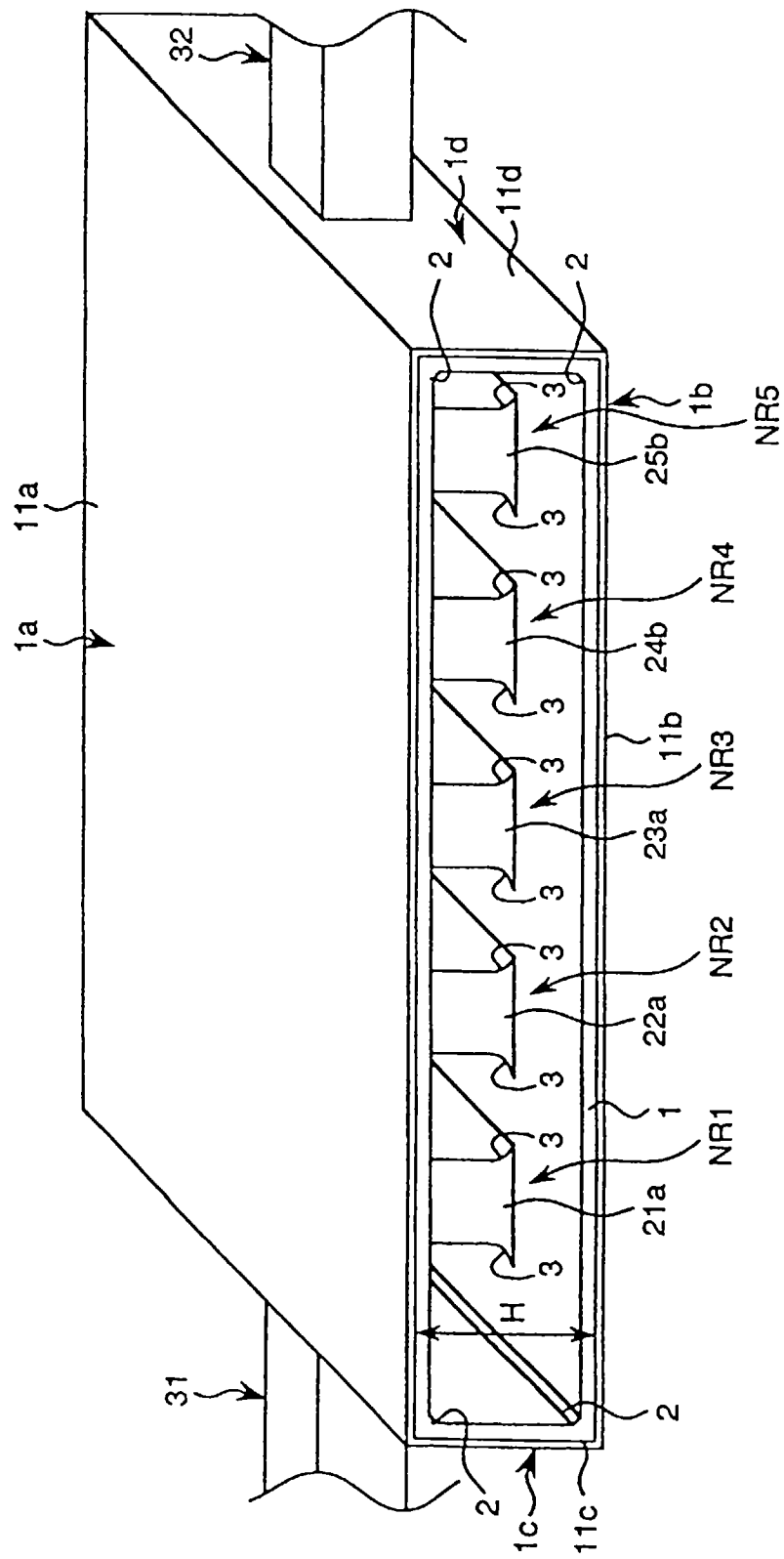


FIG. 4

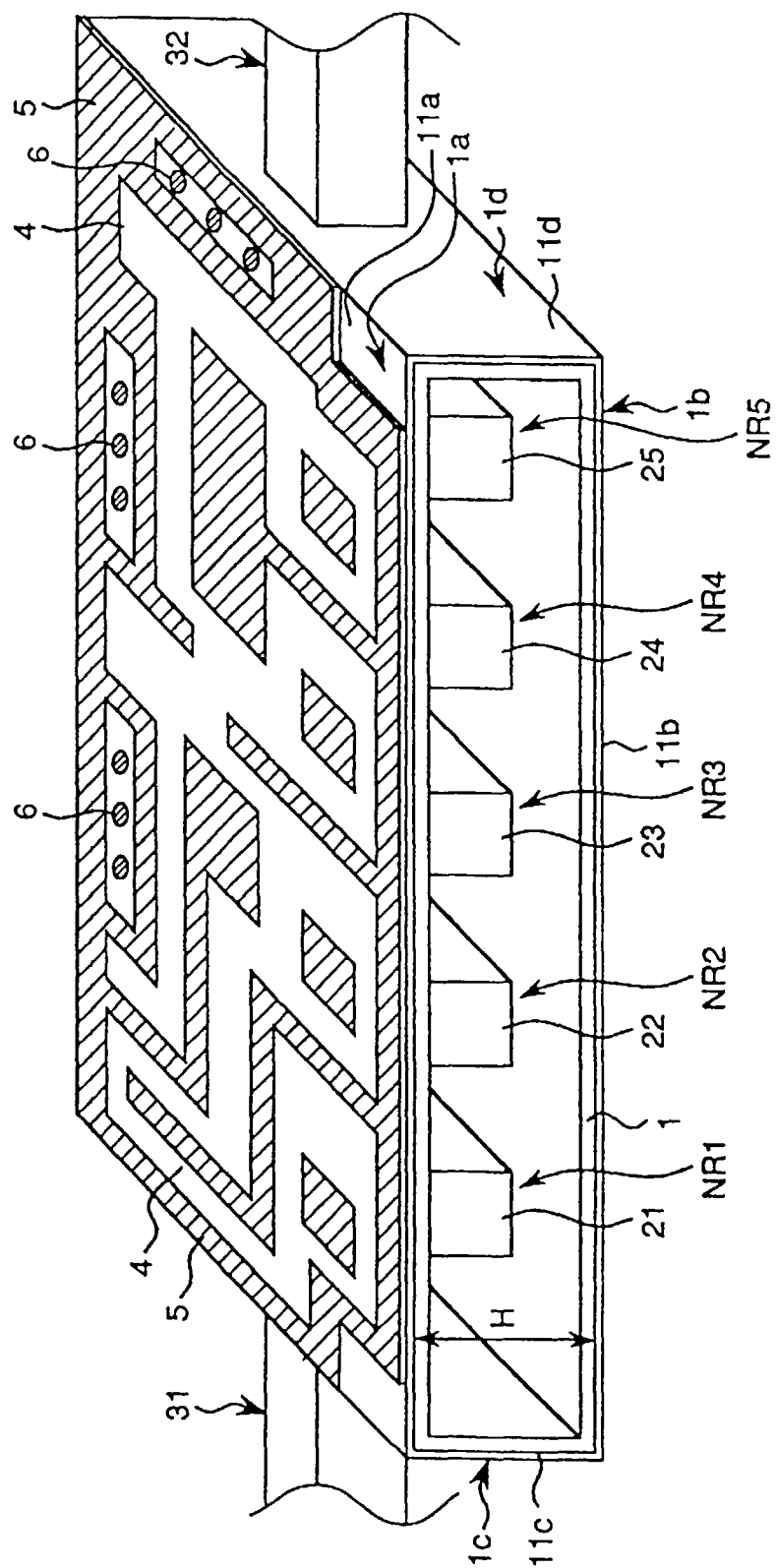


FIG. 5

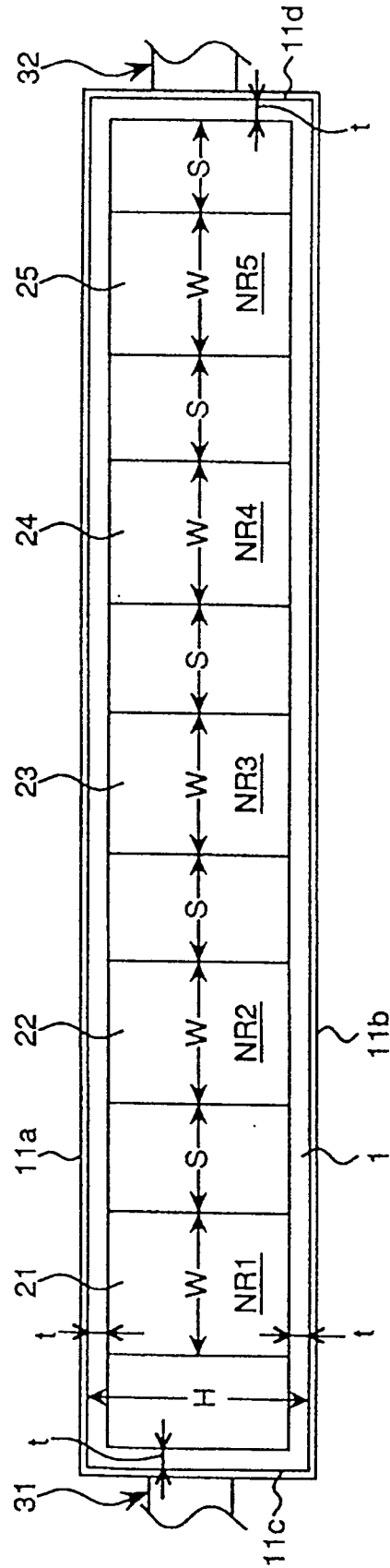


FIG. 6

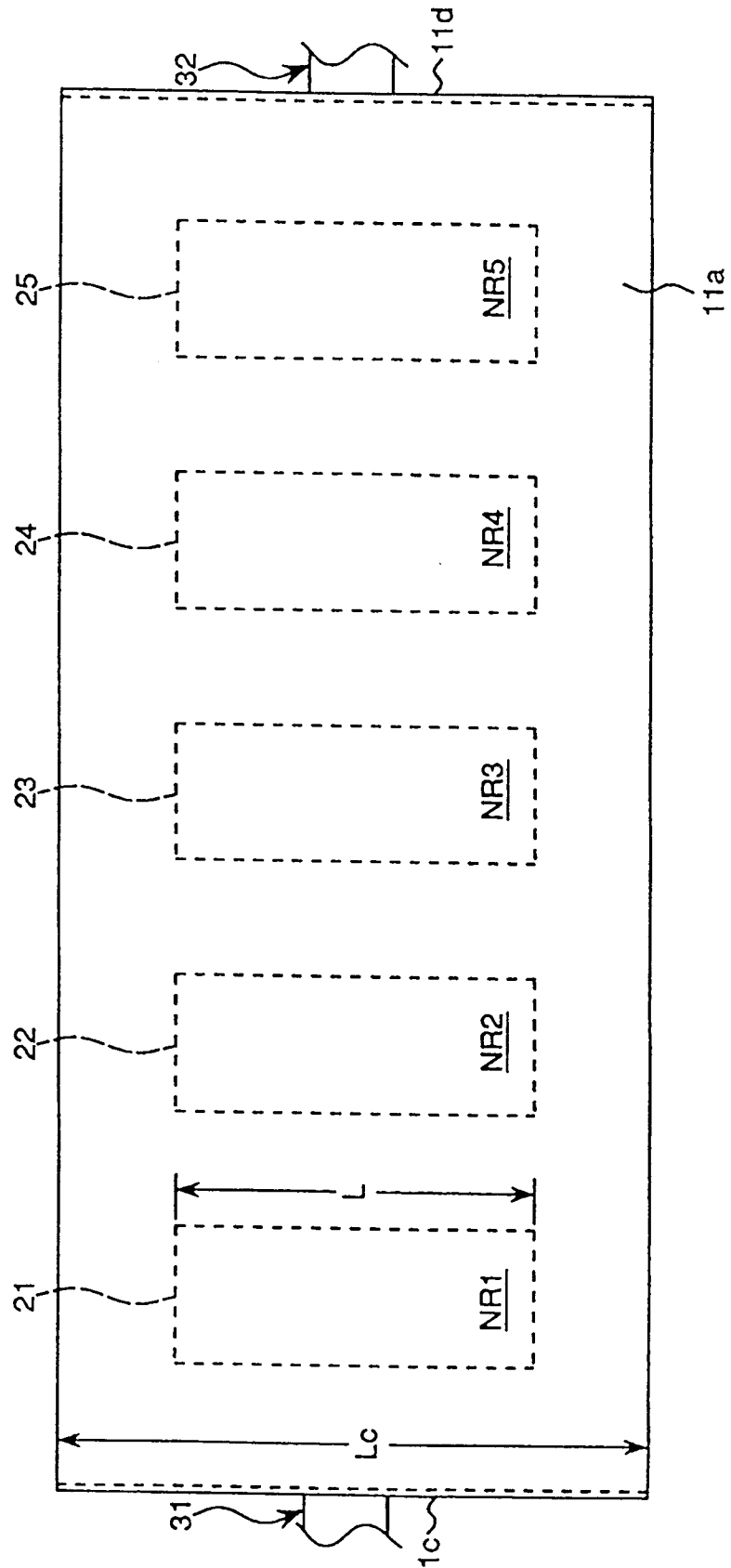


FIG. 7B

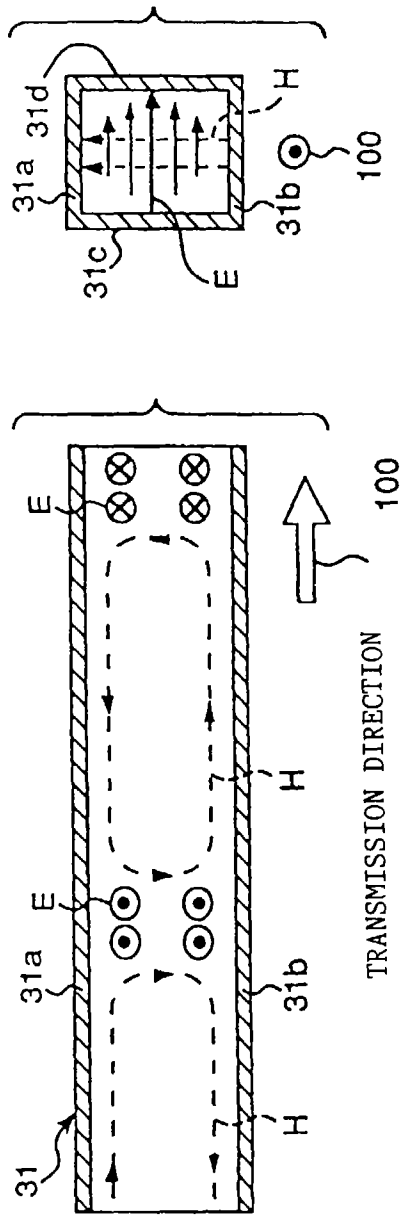


FIG. 7D

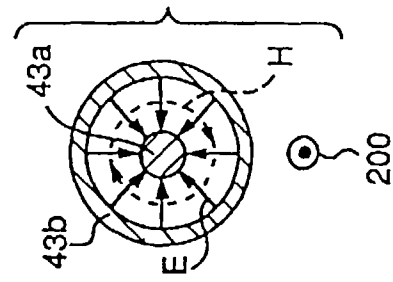


FIG. 7A

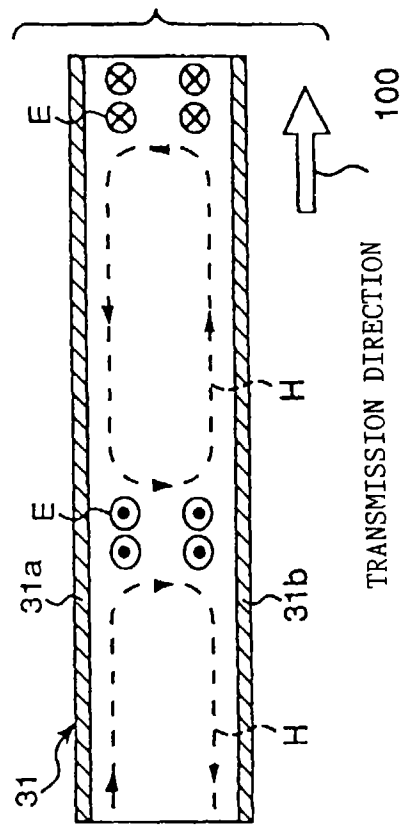
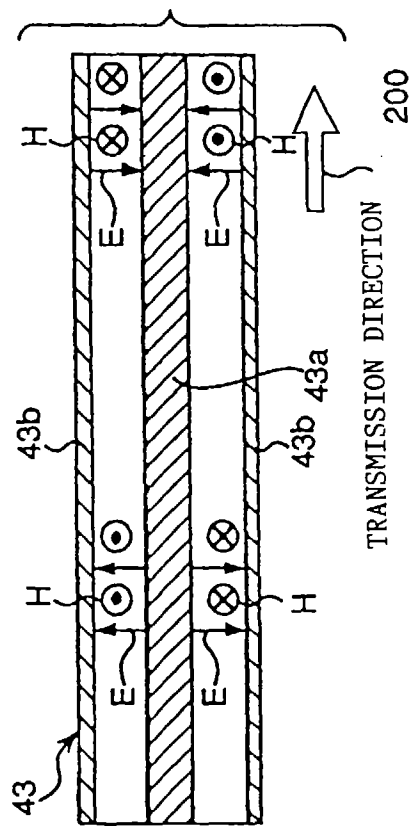


FIG. 7C



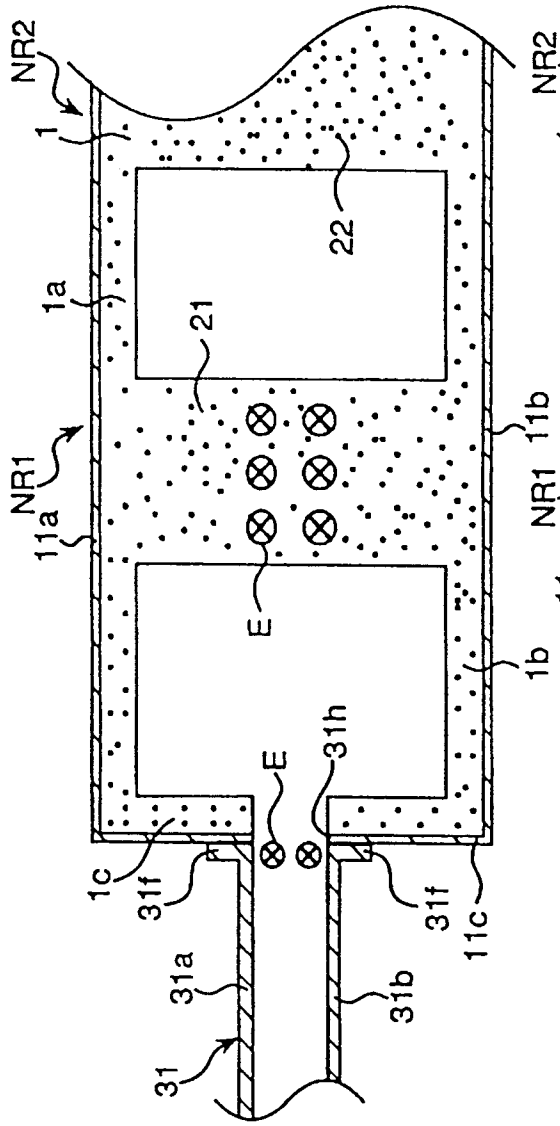


FIG. 8A

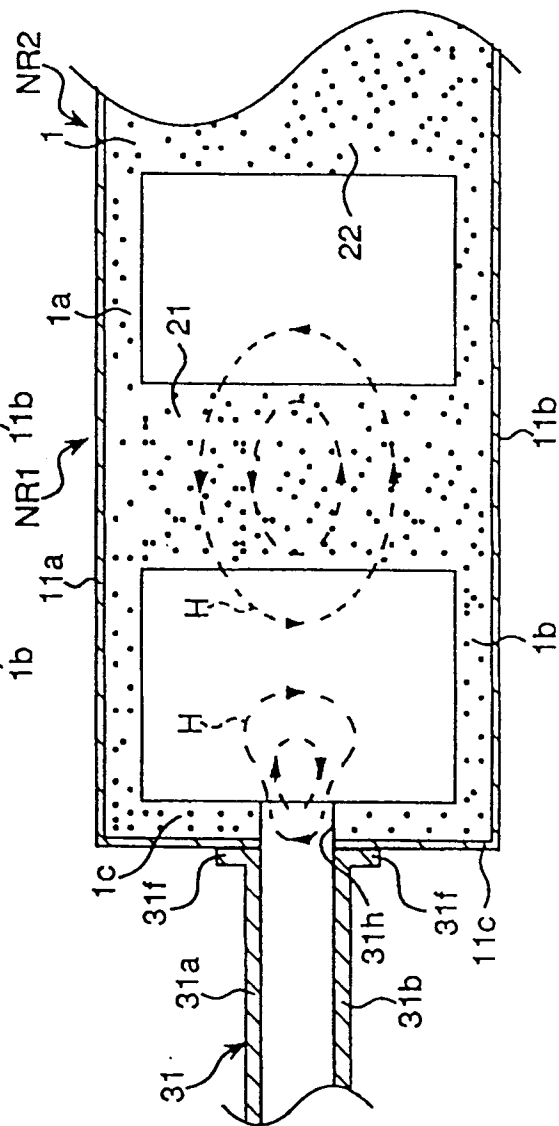


FIG. 8B

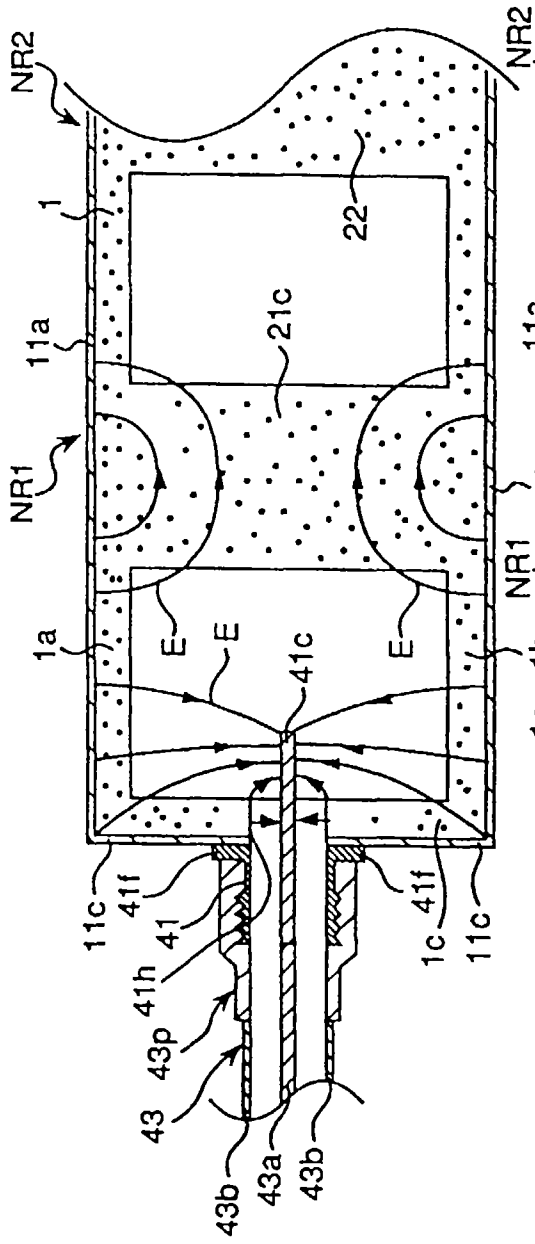


FIG. 9A

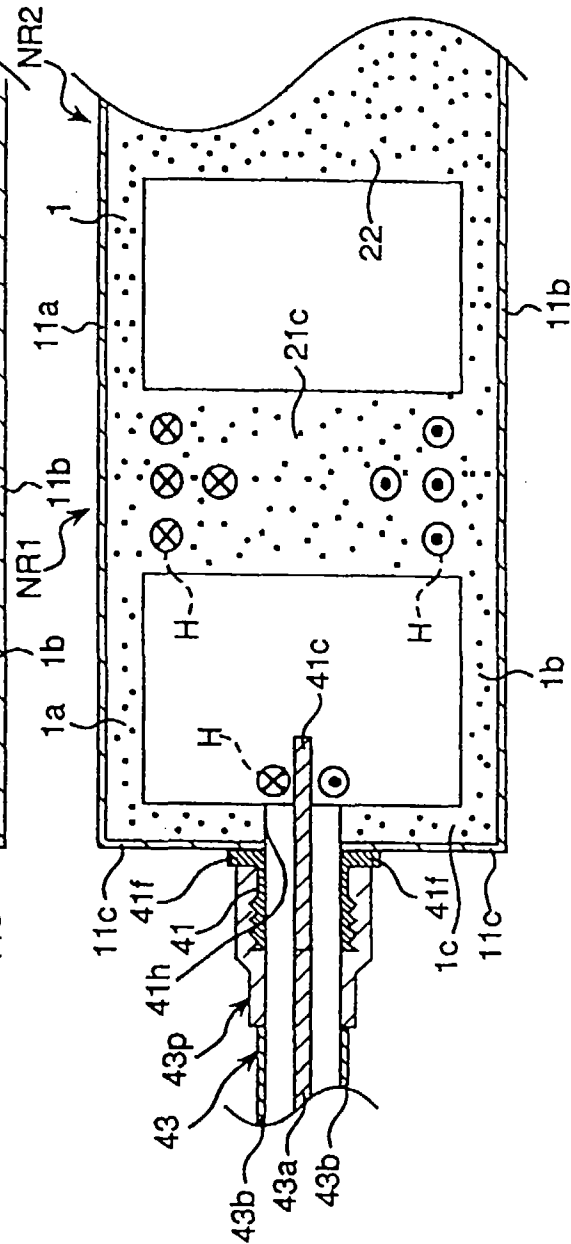


FIG. 9B

FIG. 10A

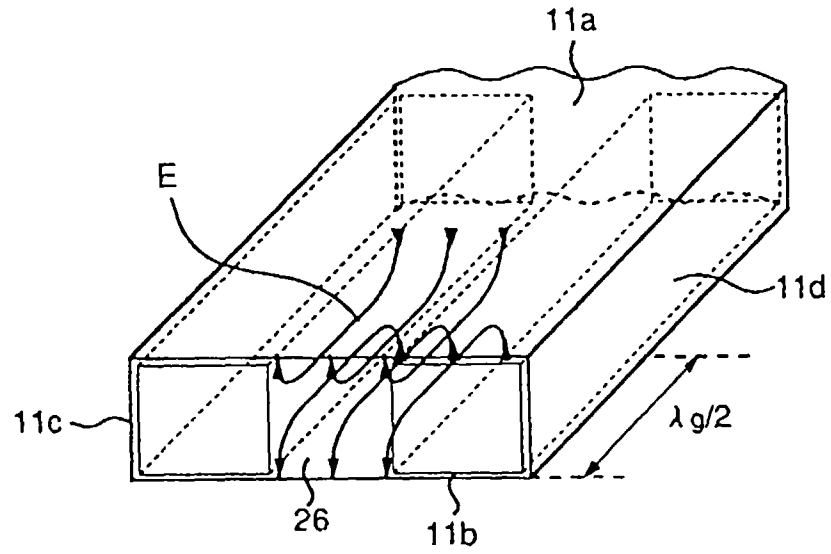


FIG. 10B

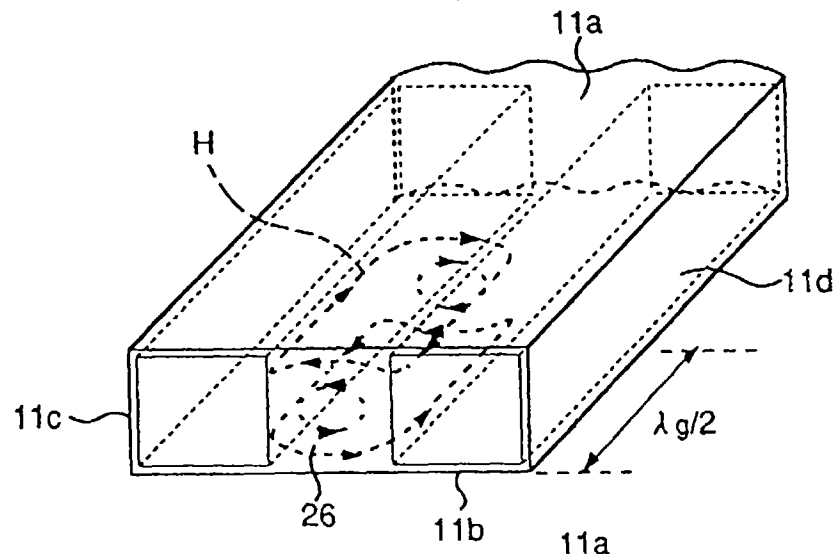


FIG. 10C

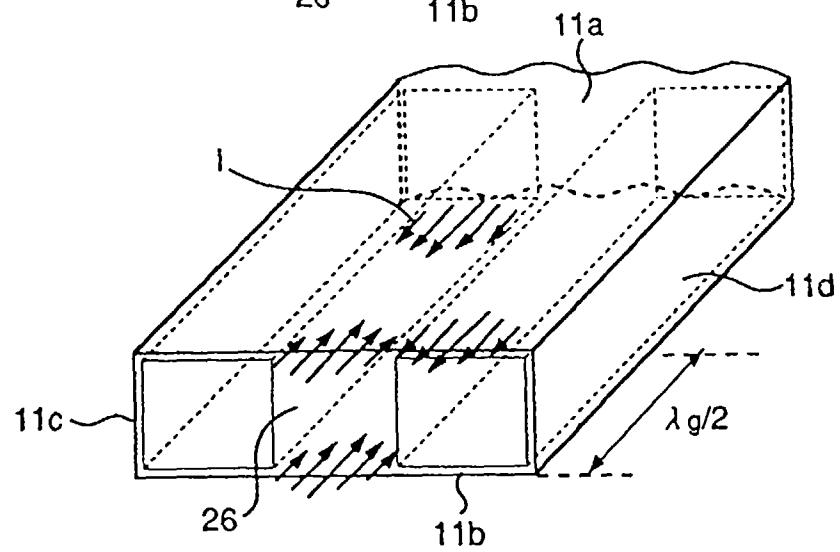


FIG. 11A

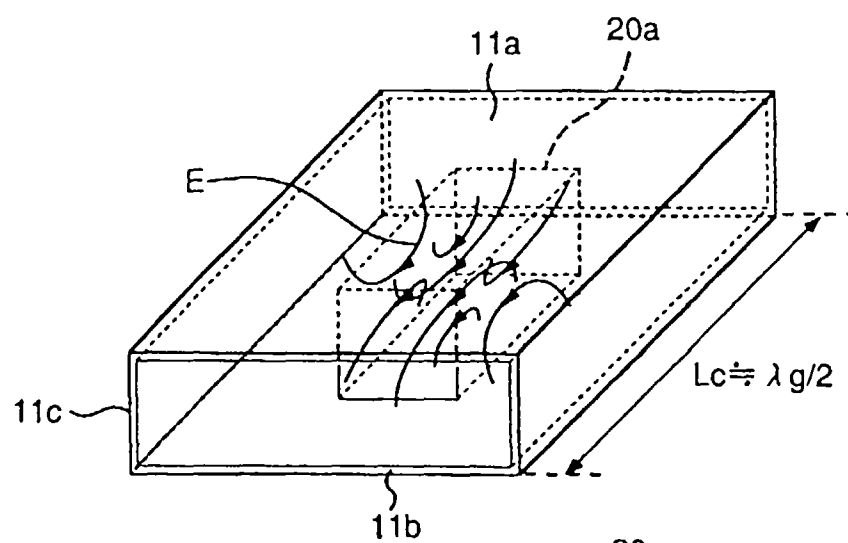


FIG. 11B

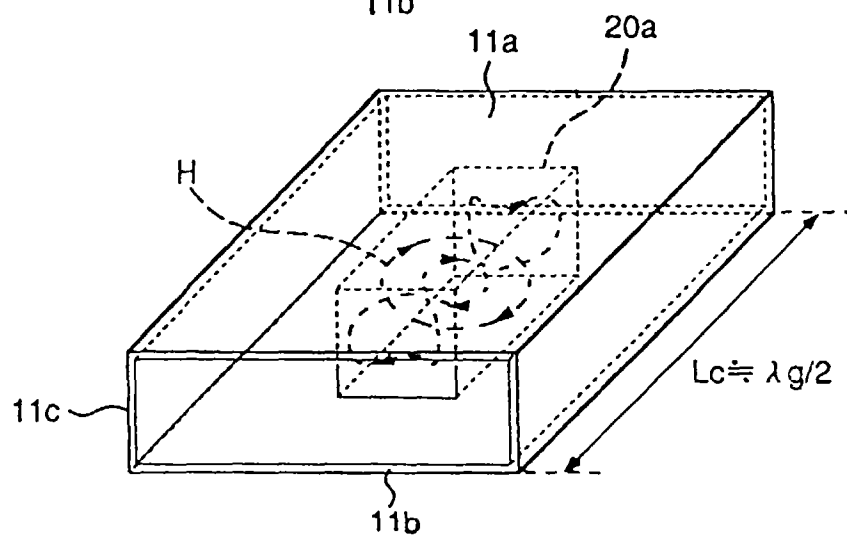


FIG. 11C

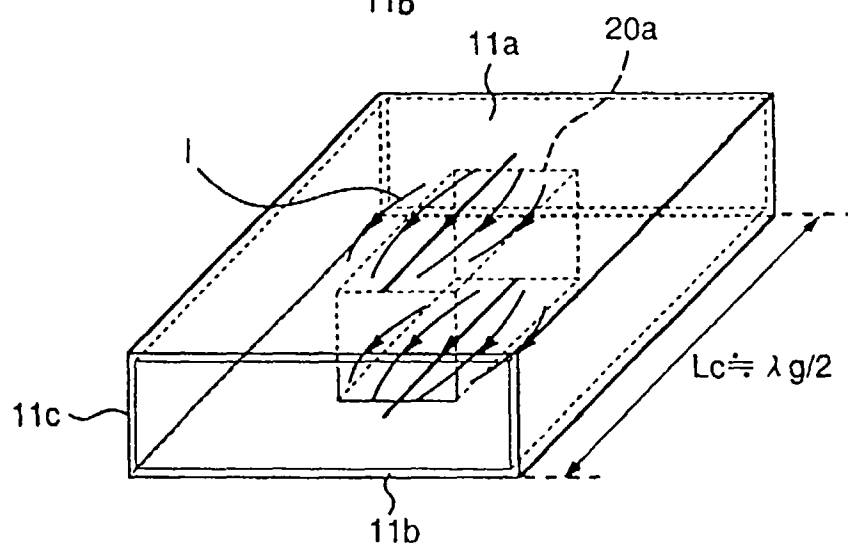


FIG. 12A

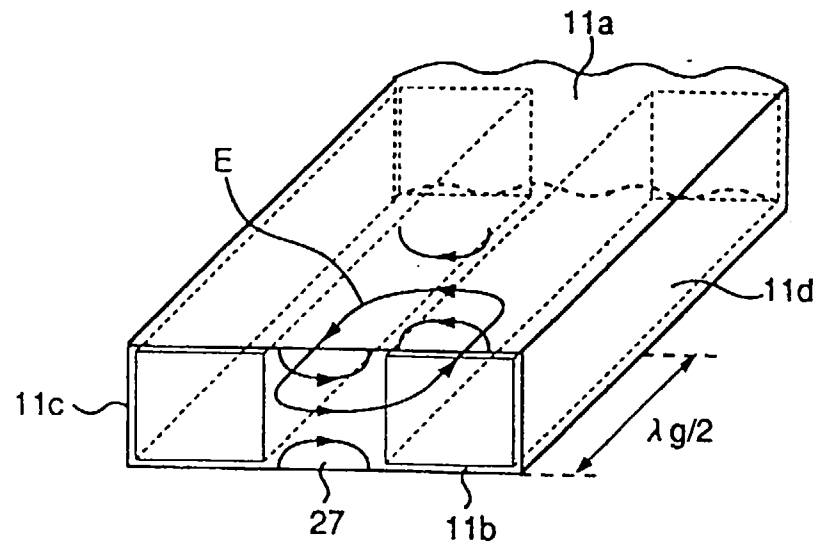


FIG. 12B

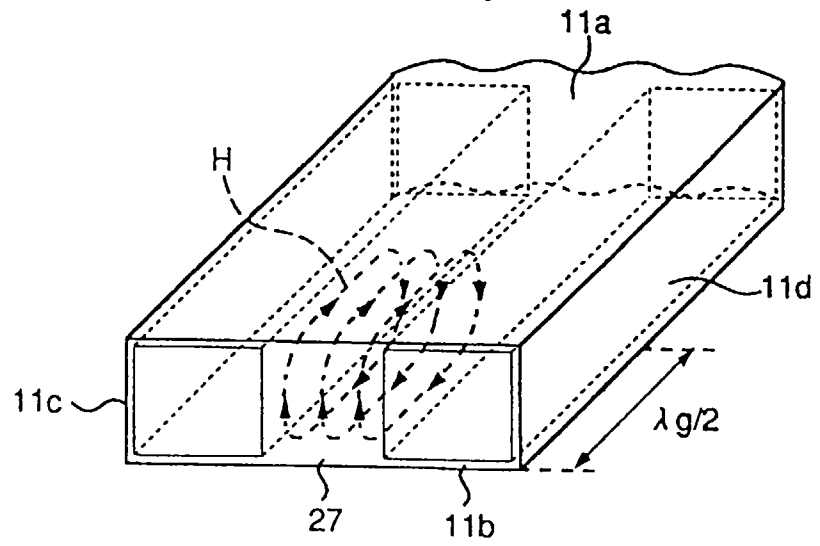


FIG. 12C

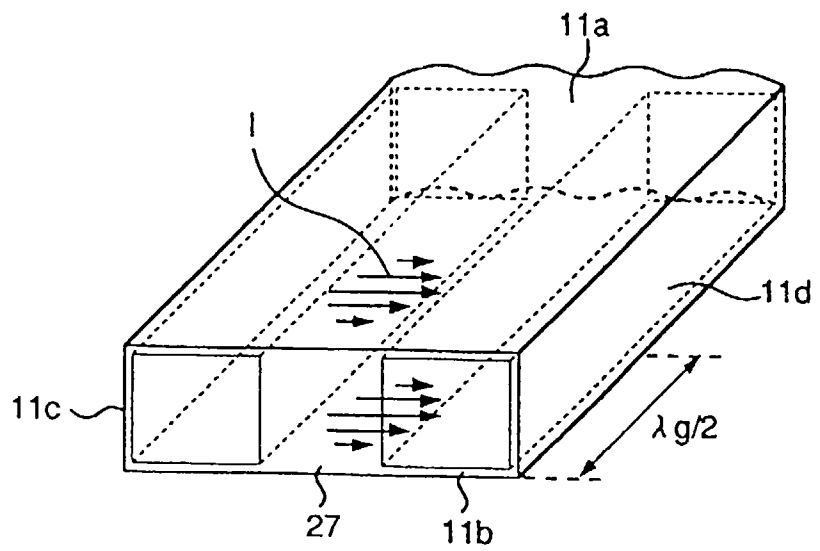


FIG. 13A

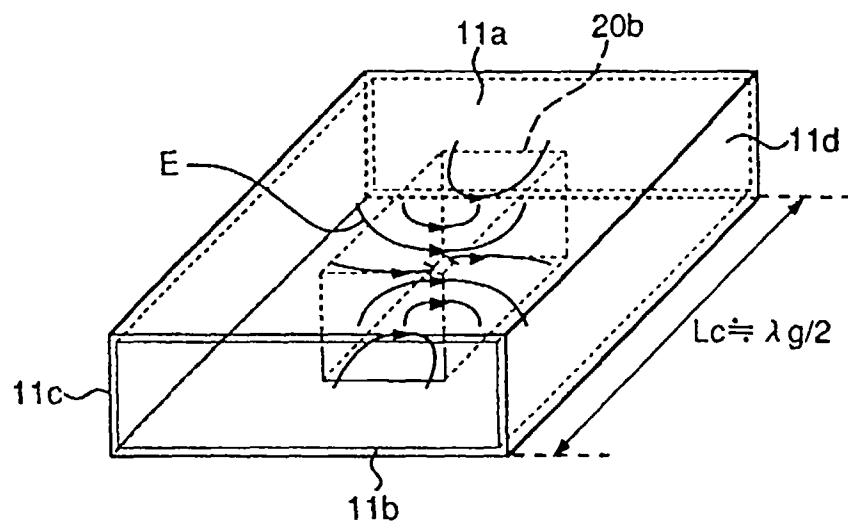


FIG. 13B

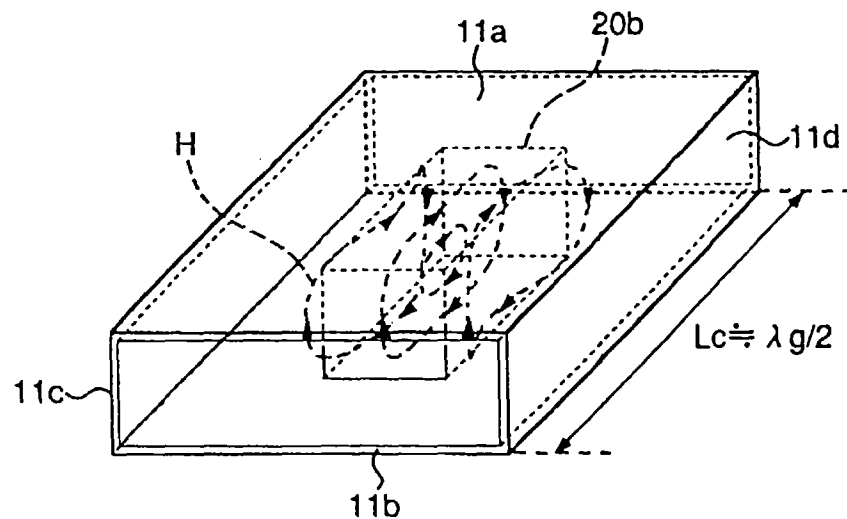


FIG. 13C

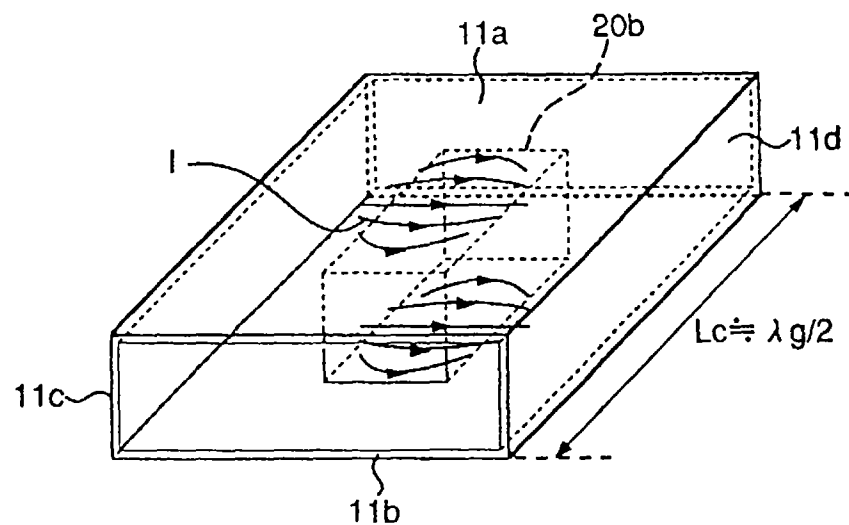


FIG. 14A

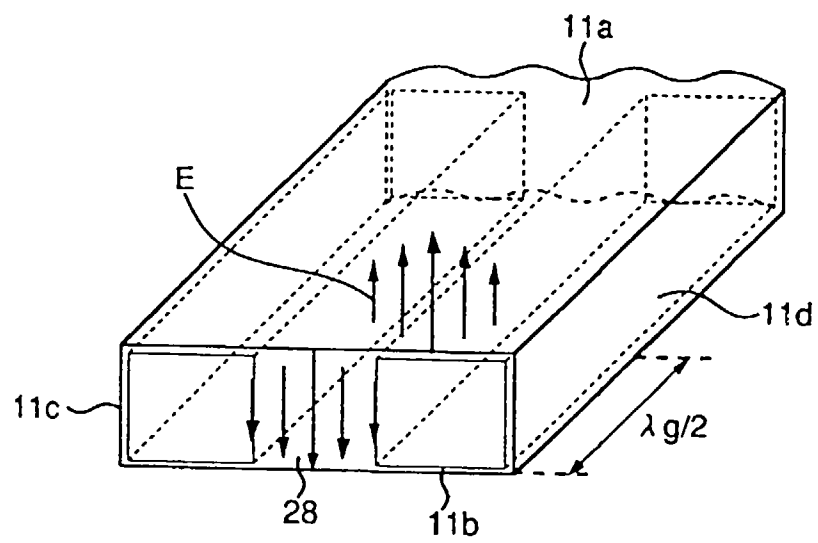


FIG. 14B

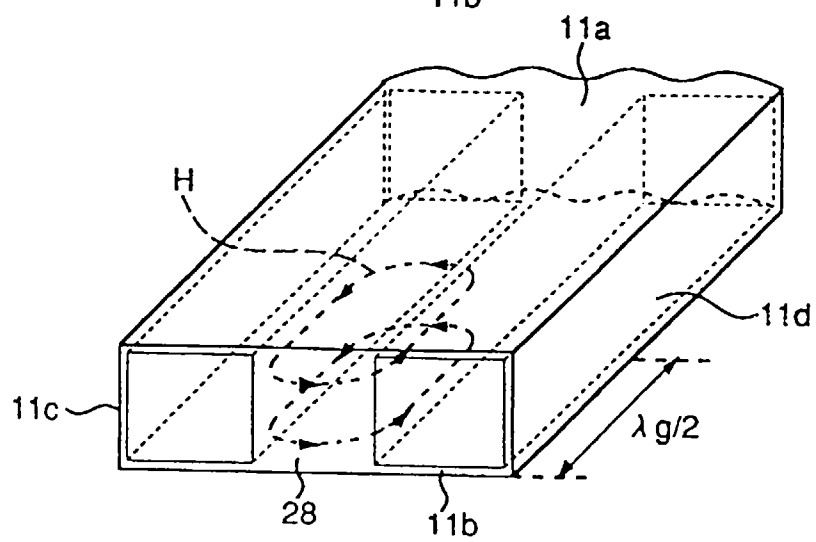


FIG. 14C

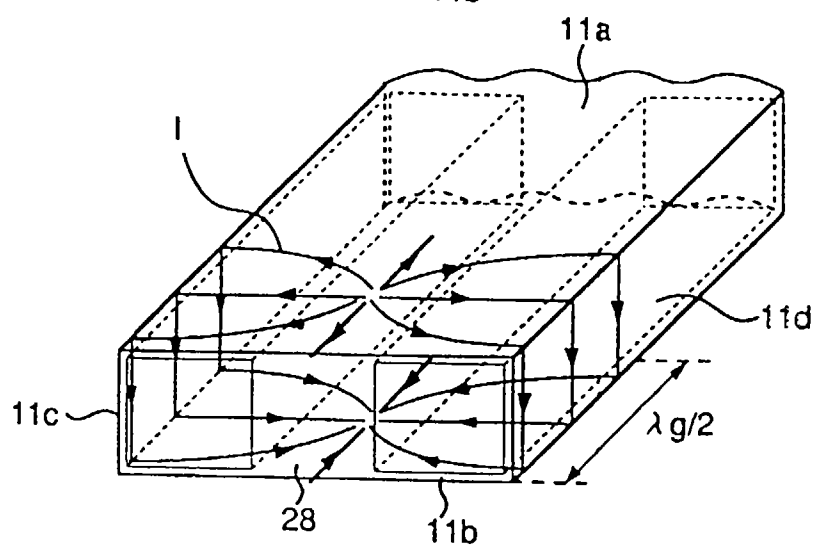


FIG. 15A

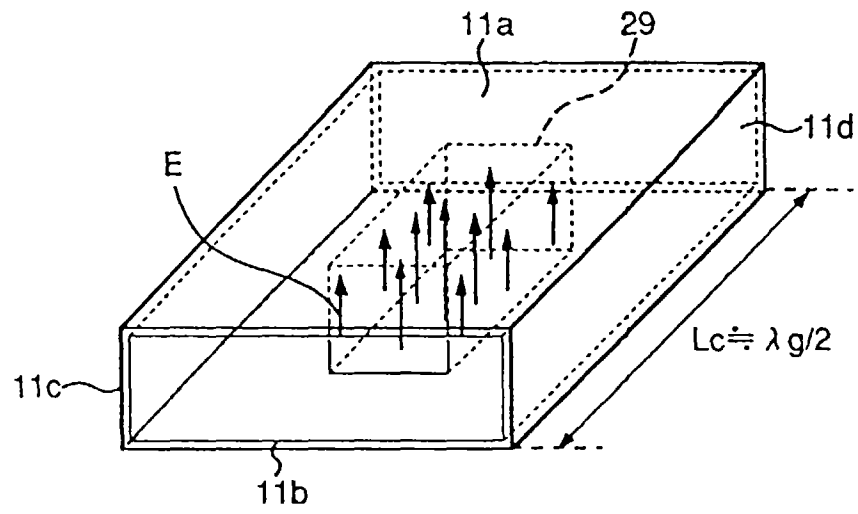


FIG. 15B

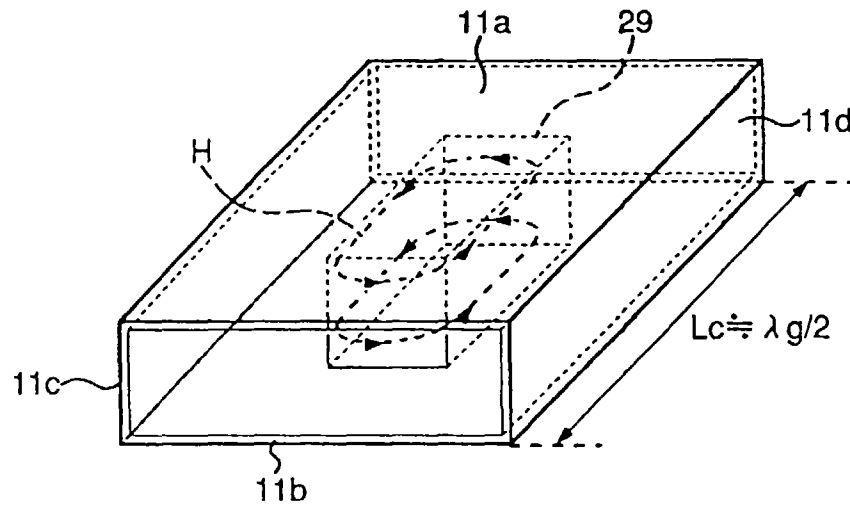


FIG. 15C

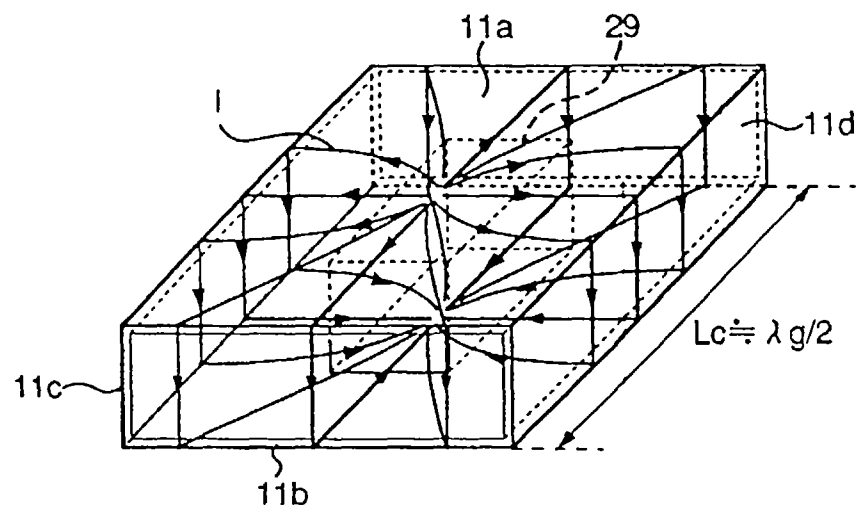


FIG. 16

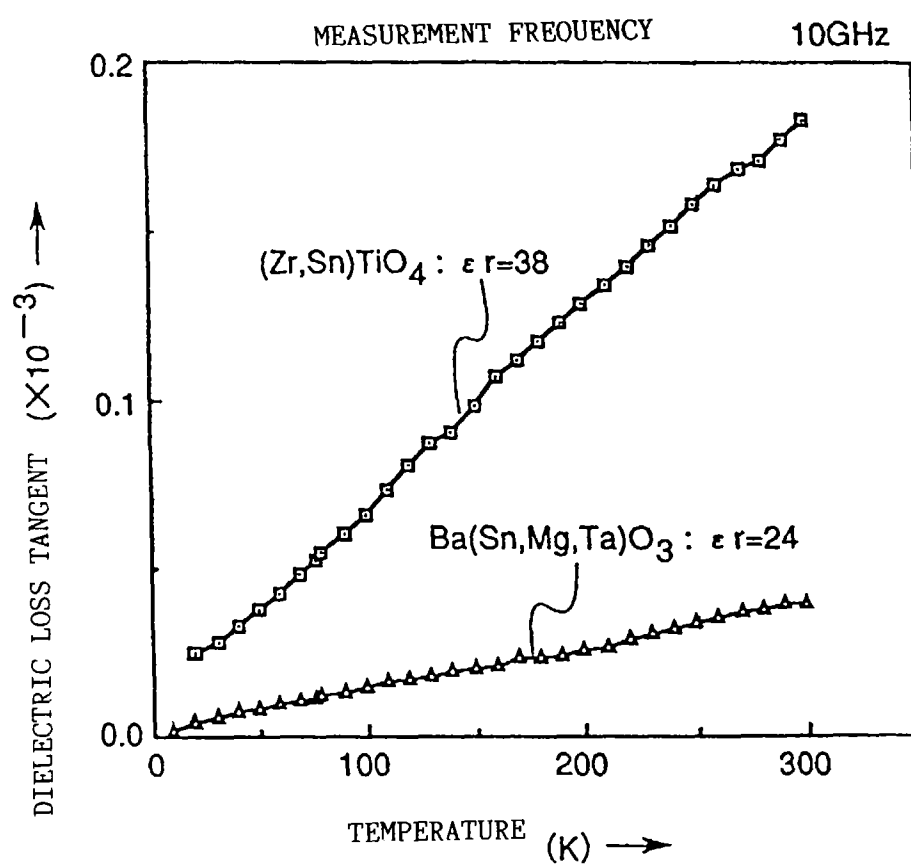


FIG. 17A PRESENT EMBODIMENT

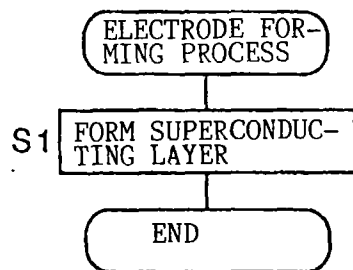


FIG. 17B COMPARATIVE EXAMPLE

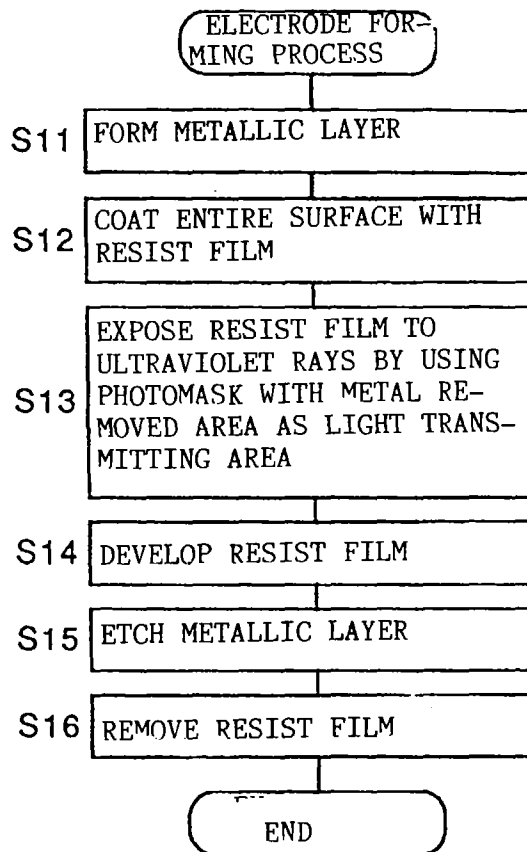


FIG. 18A

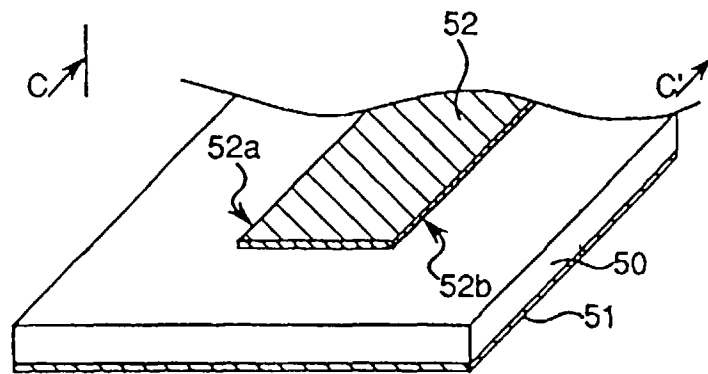


FIG. 18B

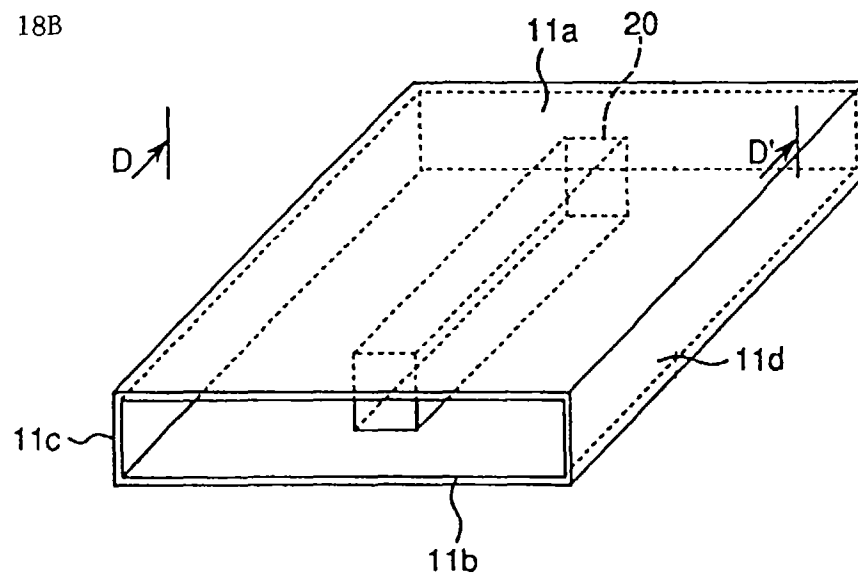


FIG. 19

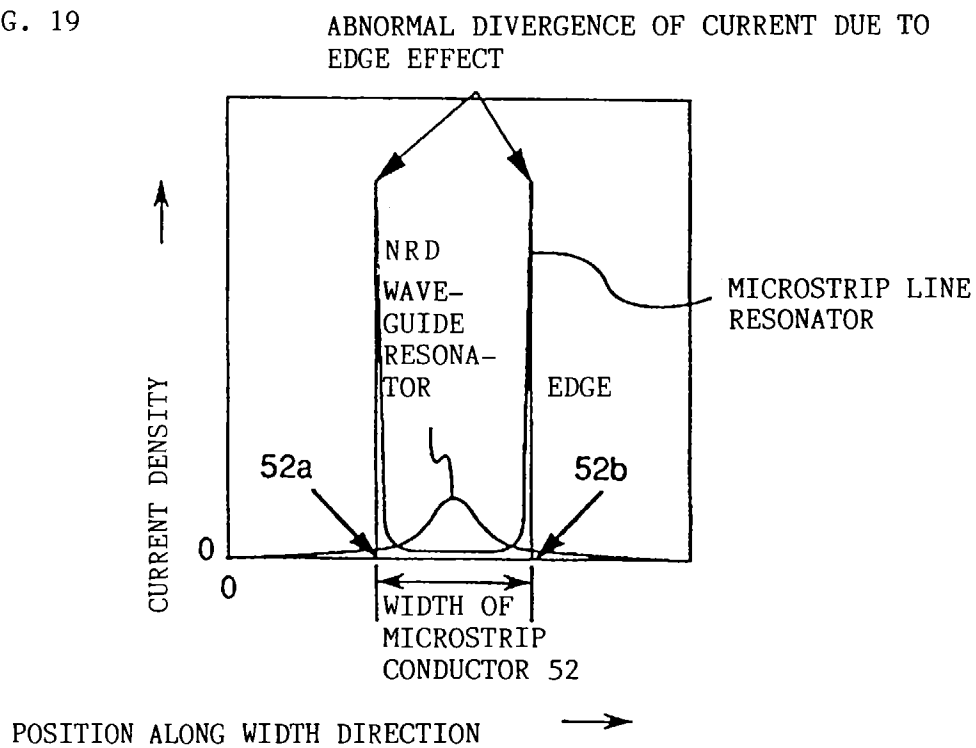


FIG. 20A

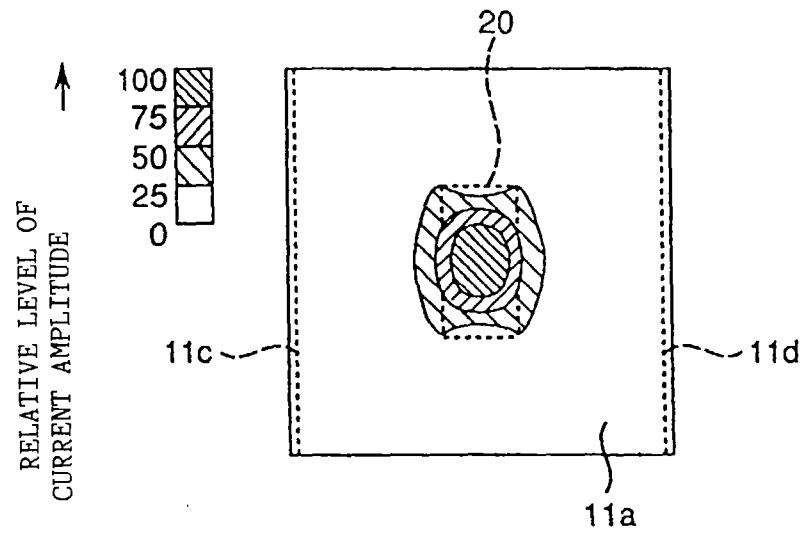


FIG. 20B

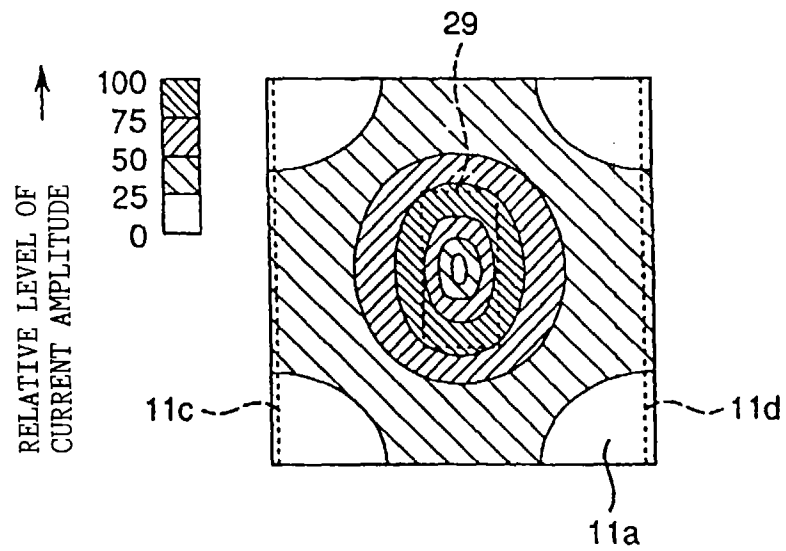


FIG. 21

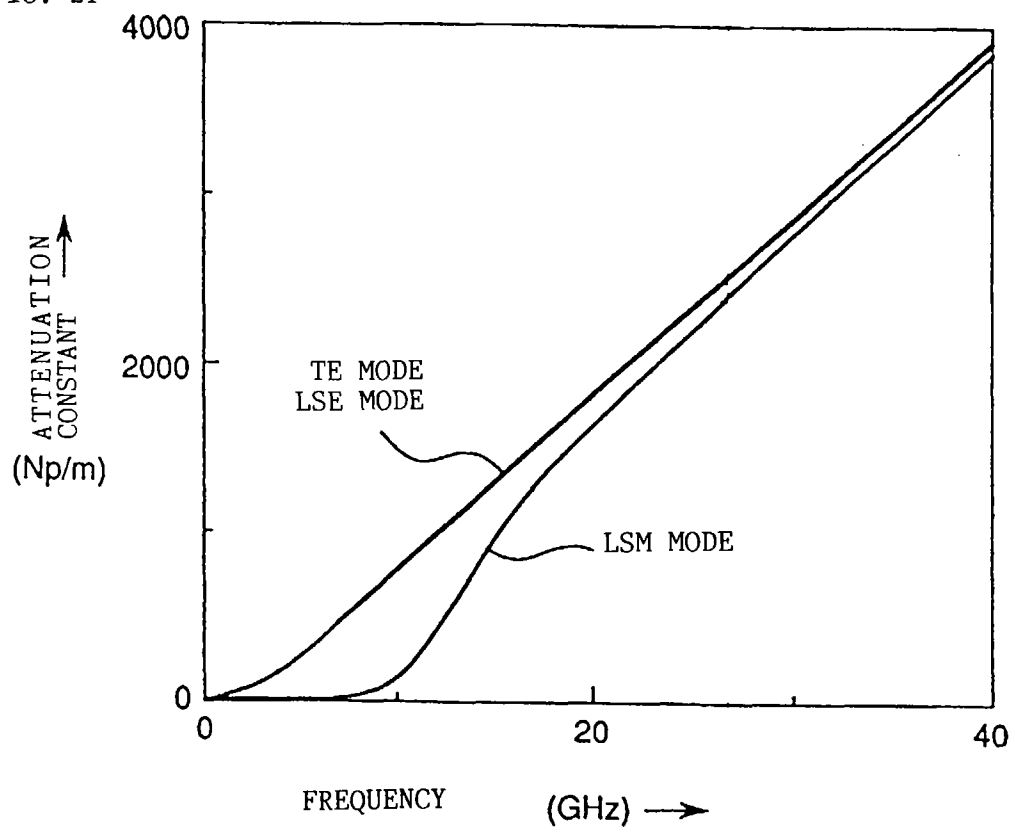


FIG. 22

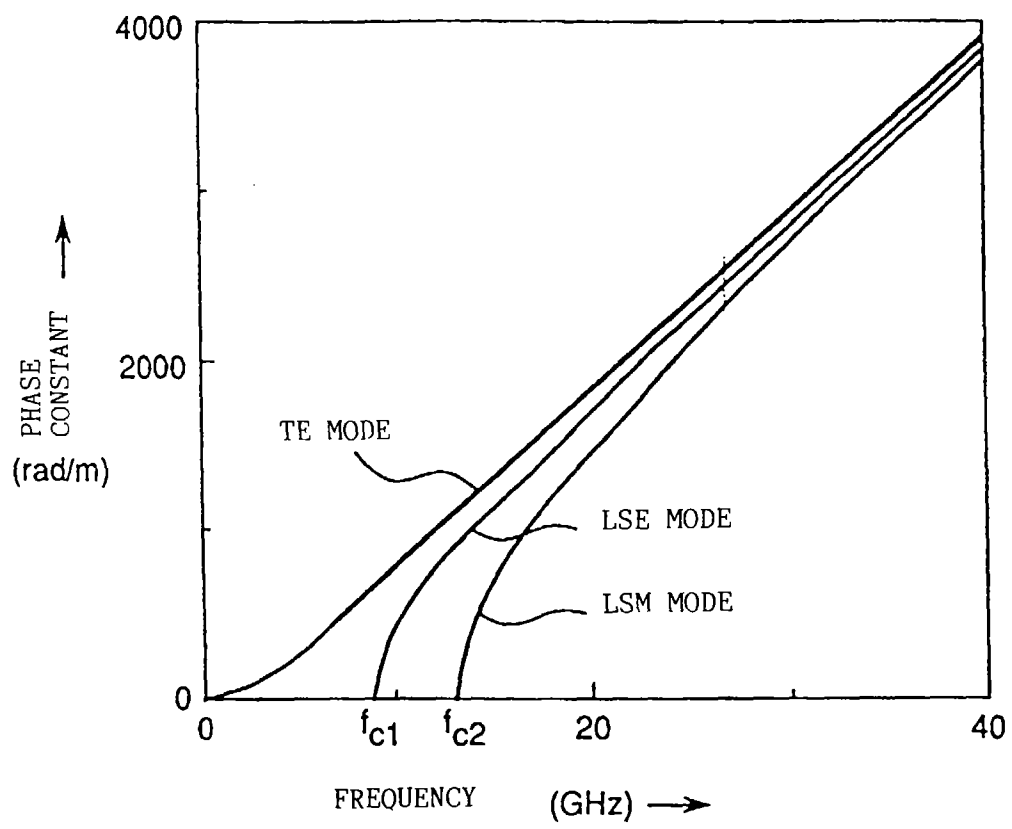


FIG. 23

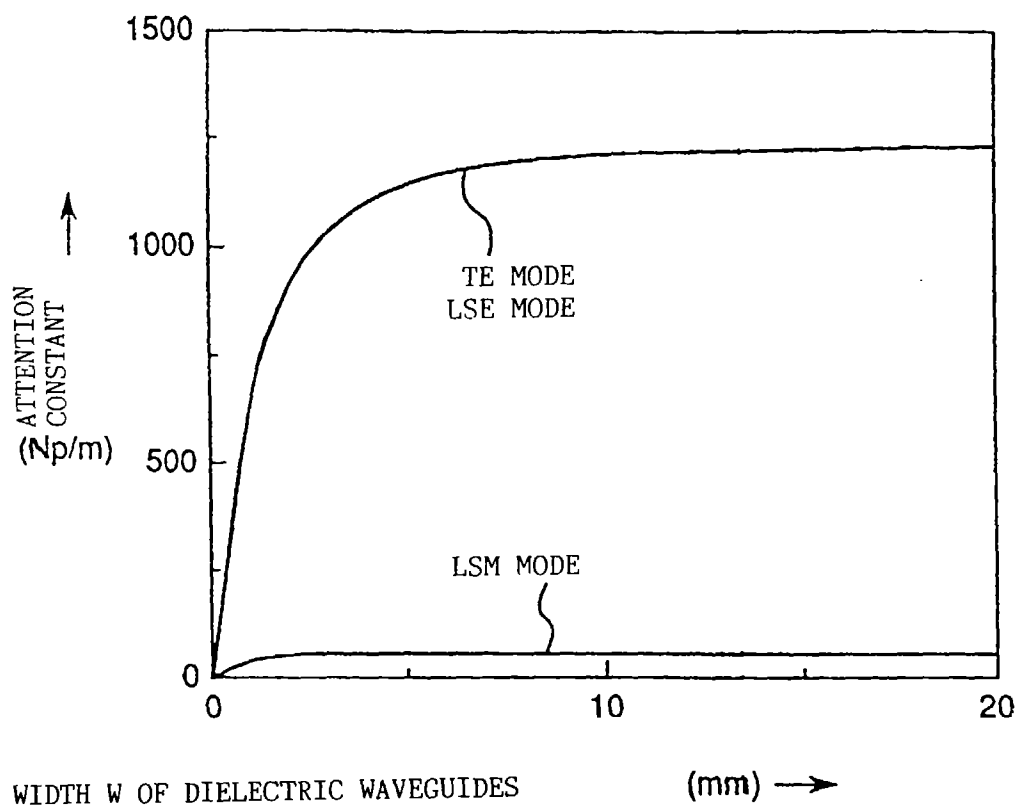


FIG. 24

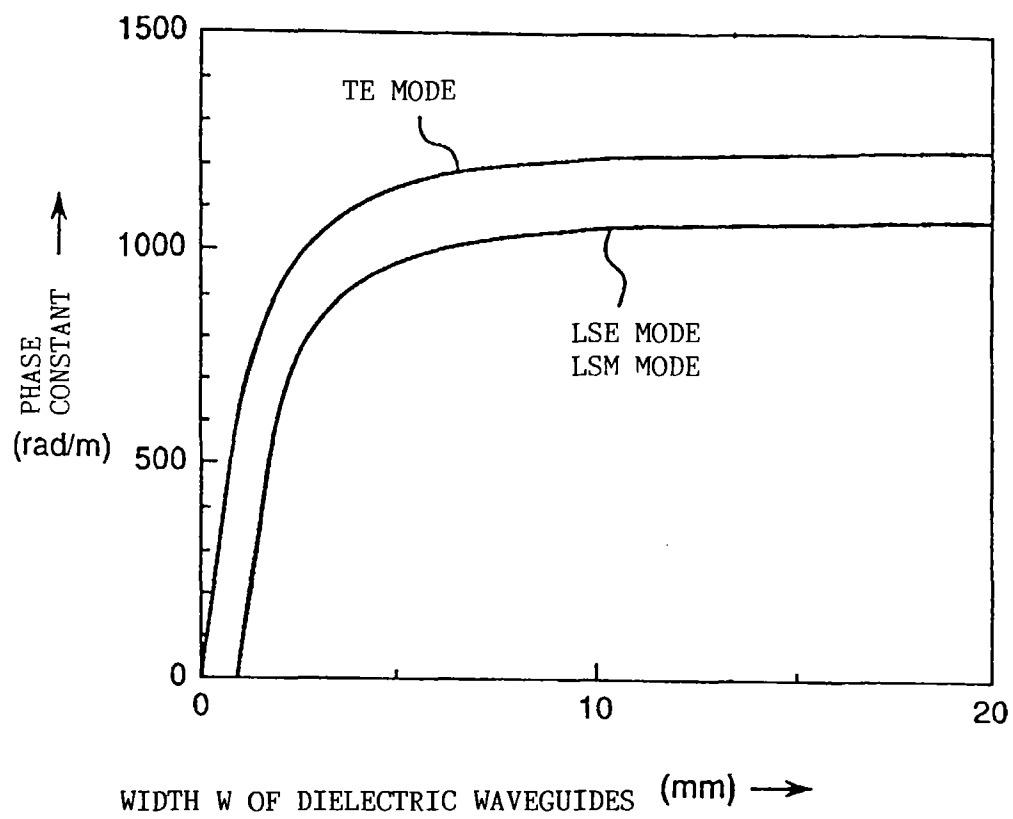


FIG. 25

